DEMETRA
Mitigation of the Radioactivity Effects in Quantum Bits

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Istituto Nazionale di Fisica Nucleare - Roma

23/05/2019 Jaca, Spain

Istituto Nazionale di Fisica Nucleare

QUANTUM BITS

Fundamental unit of information in a quantum computer
To work: strongly coupled to other qubits (entanglement), decoupled from the world
How: *Any* two level quantum system

- **Ions in traps**
- **Rydberg atoms**
- **Electron spin in quantum dots**
- **…**
- **Superconducting circuits**

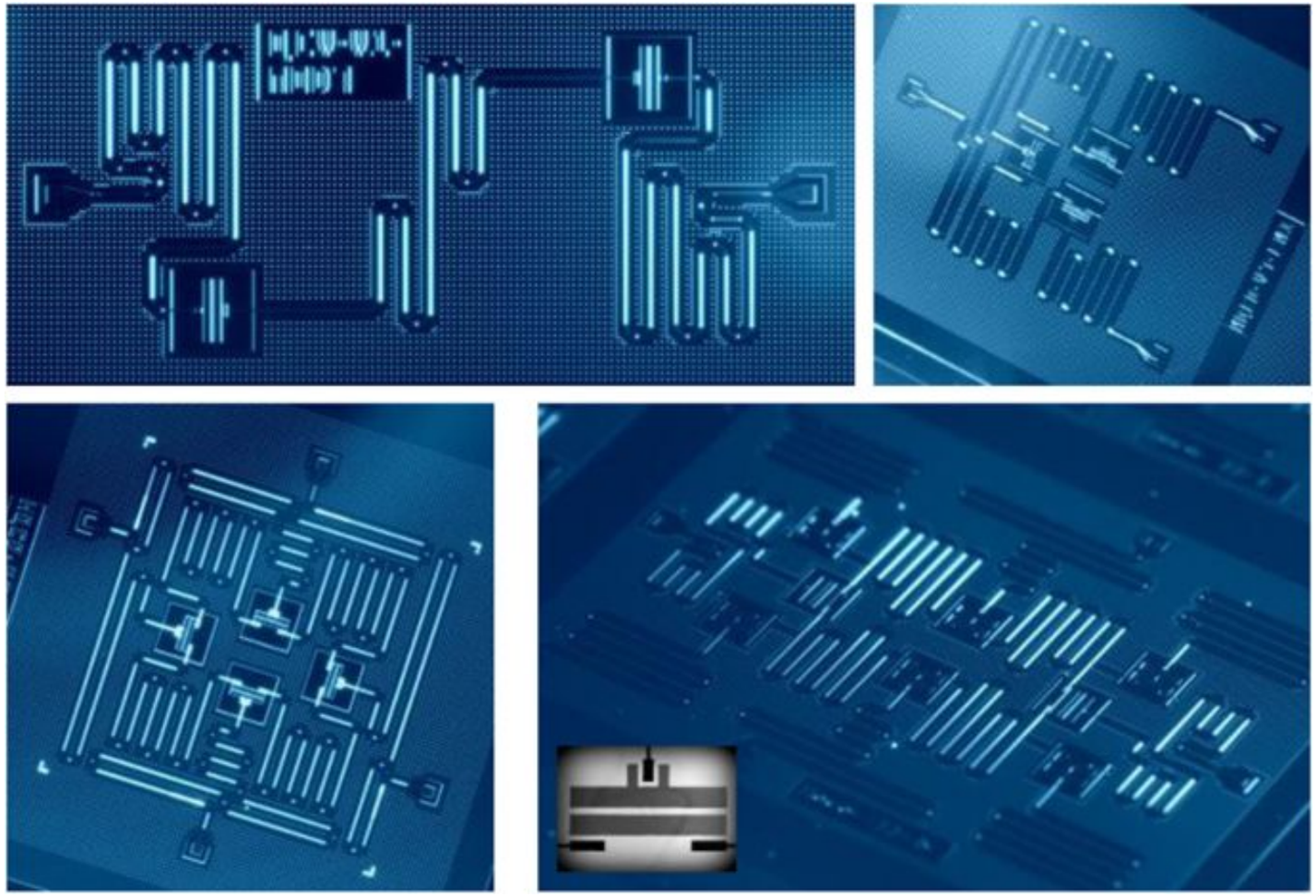
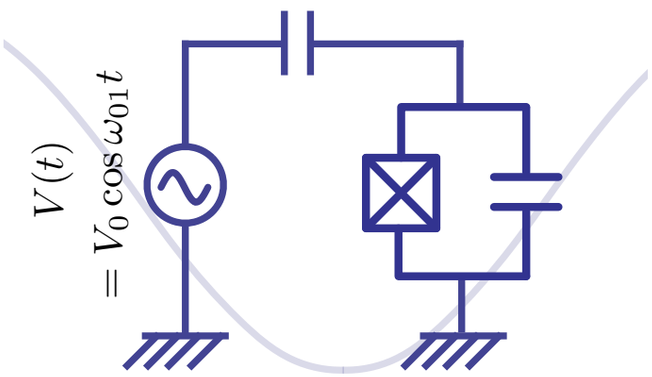
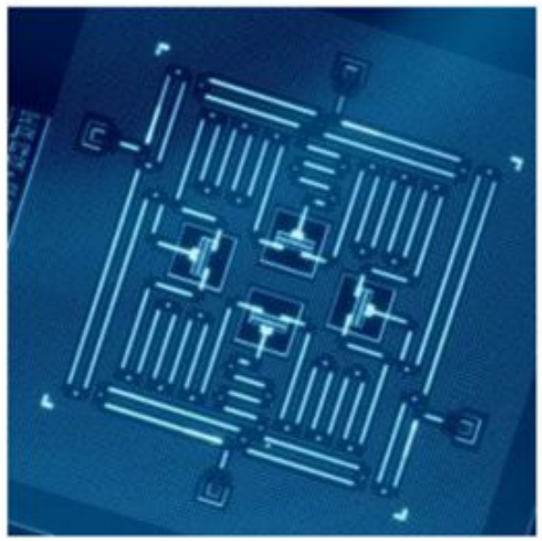


Image from J.Gambetta, https://www.nature.com/articles/s41534-016-0004-0

SUPERCONDUCTING QUBITS



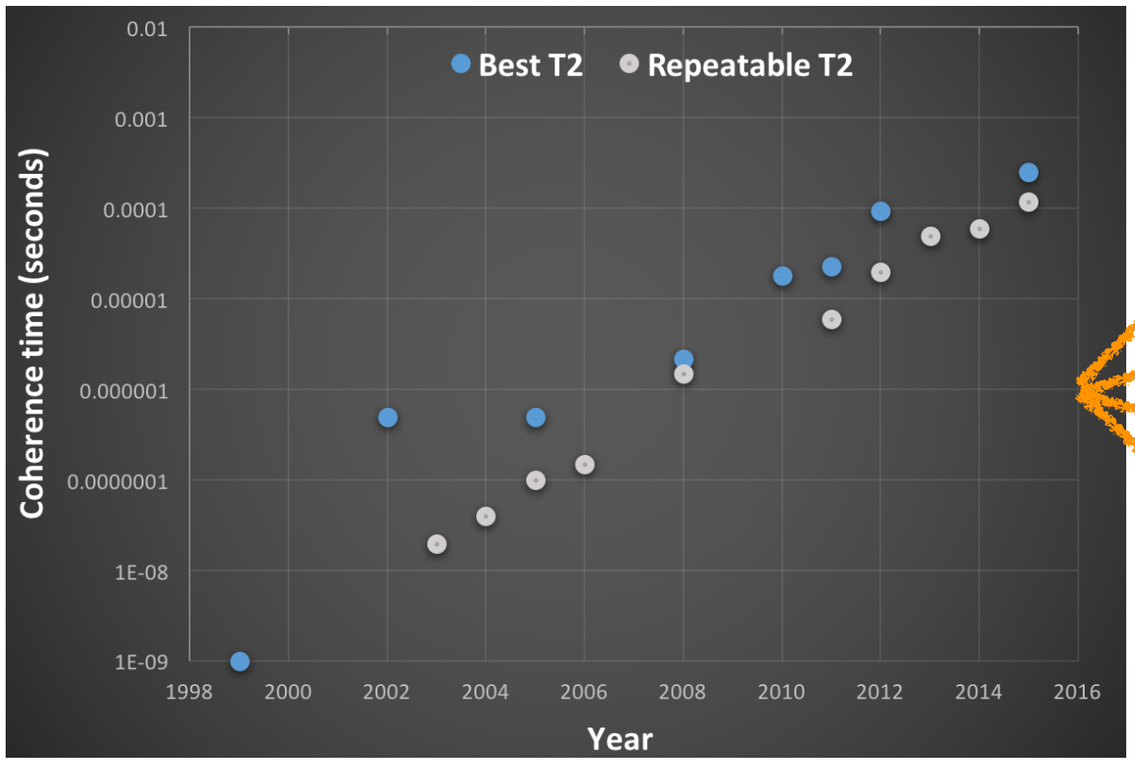


- Macroscopic circuits
- Tens of nm of superconductor deposited on dielectric substrate, operated in cryostats
- Easy to design, fabricate, assemble
- Easy to inter-couple: wires, L, C…

IBM-Q 20 qubits

SUPERCONDUCTING QUBITS

But limited coherence time!

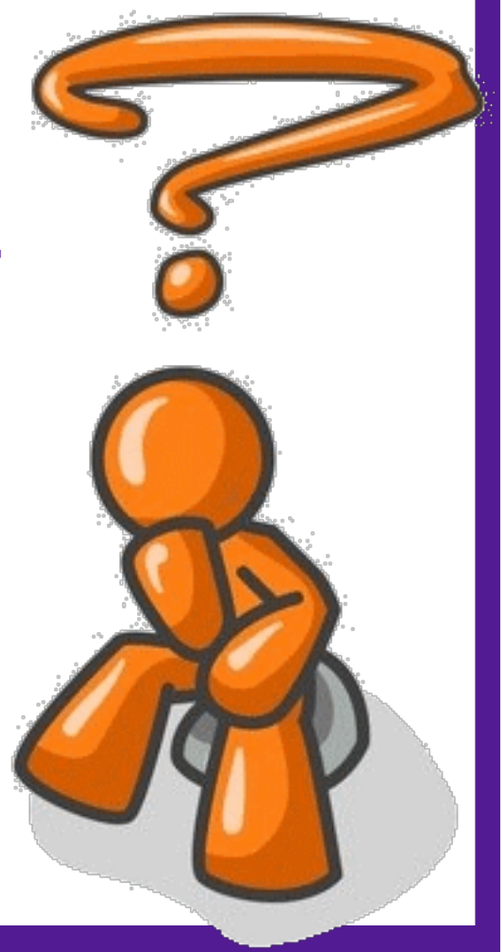


Dielectric two-level system

Paramagnetic molecules at the interface

Vortices trapped in the superconductor

Quasiparticles



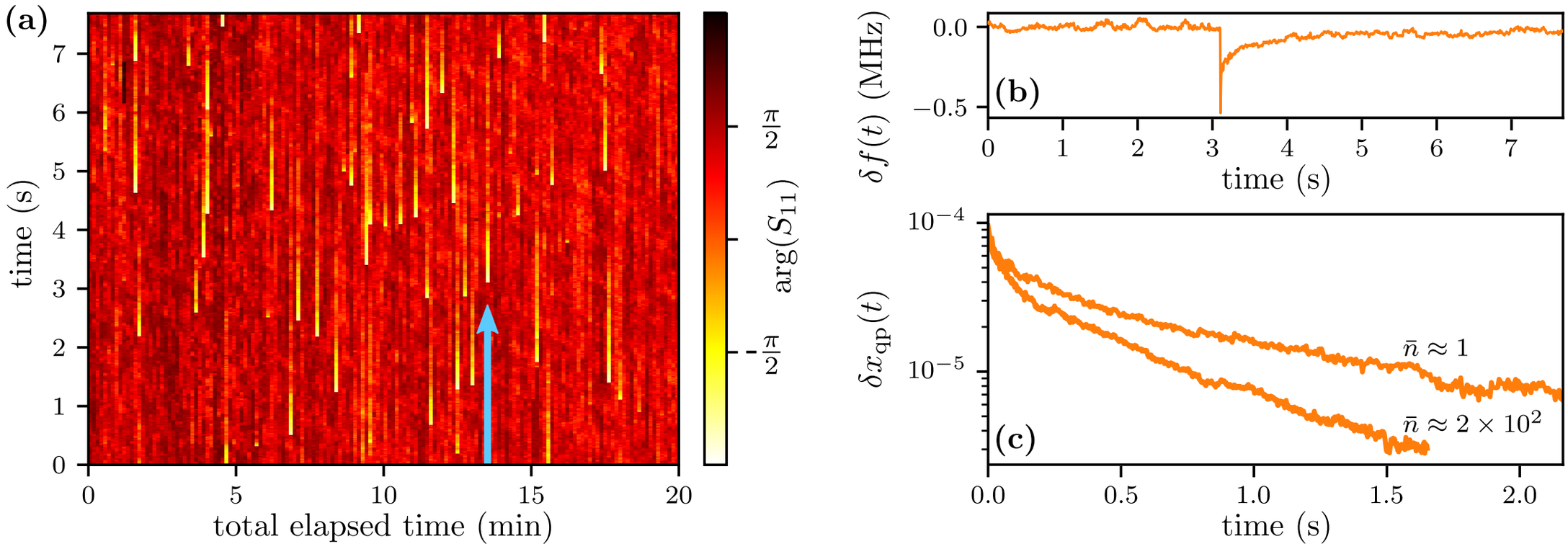
In this talk, focus on quasiparticles

EVIDENCES FOR QUASIPARTICLES

Superconductor cooled to mK temperature —> electrons bound in Cooper pairs

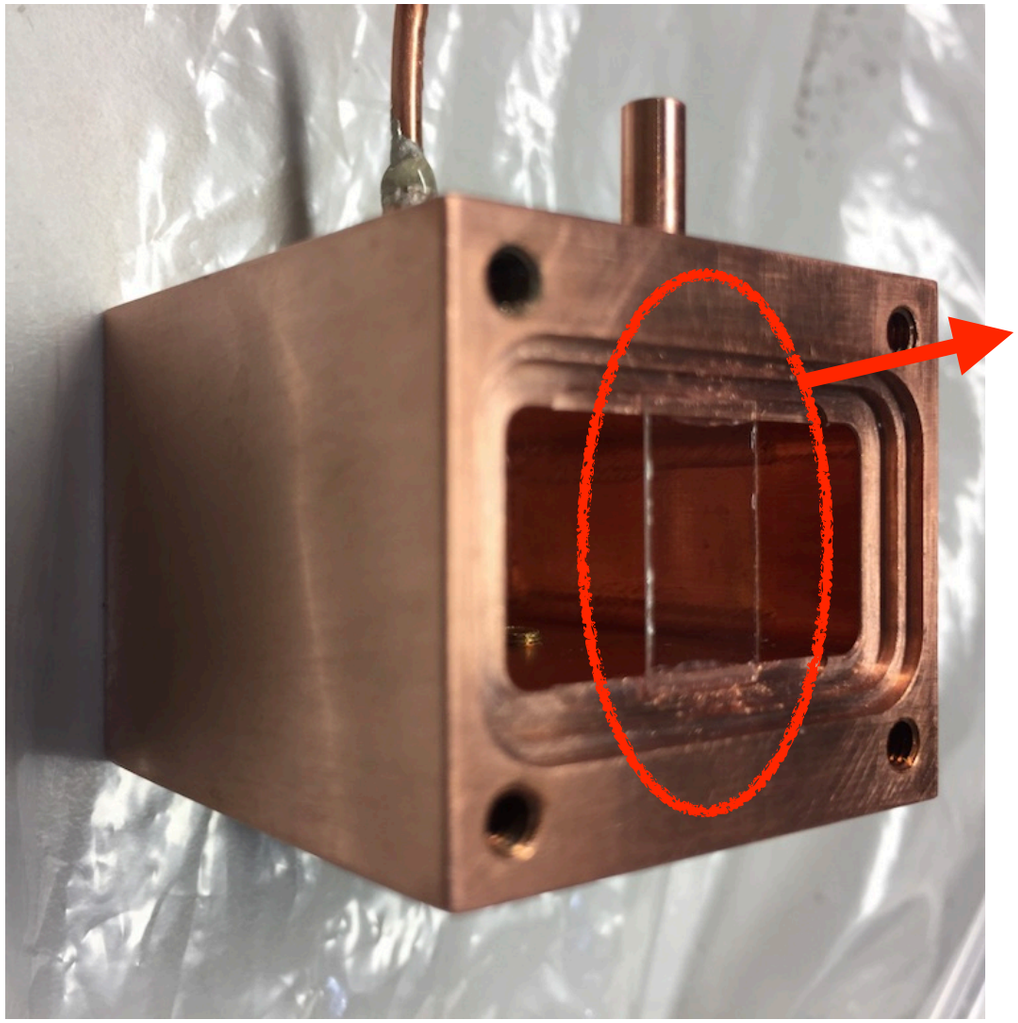
But many mechanisms can break Cooper pairs, producing quasiparticles

Pop 2018 doi:10.1103/PhysRevLett.121.117001

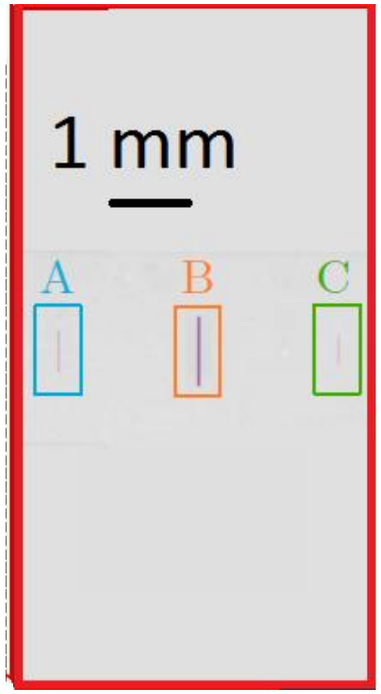


What is the origin of quasiparticles bursts?
How will they impact the performance of qubits?

QUASIPARTICLES CREATED BY RADIOACTIVITY



Superconducting resonators deposited on sapphire insulator



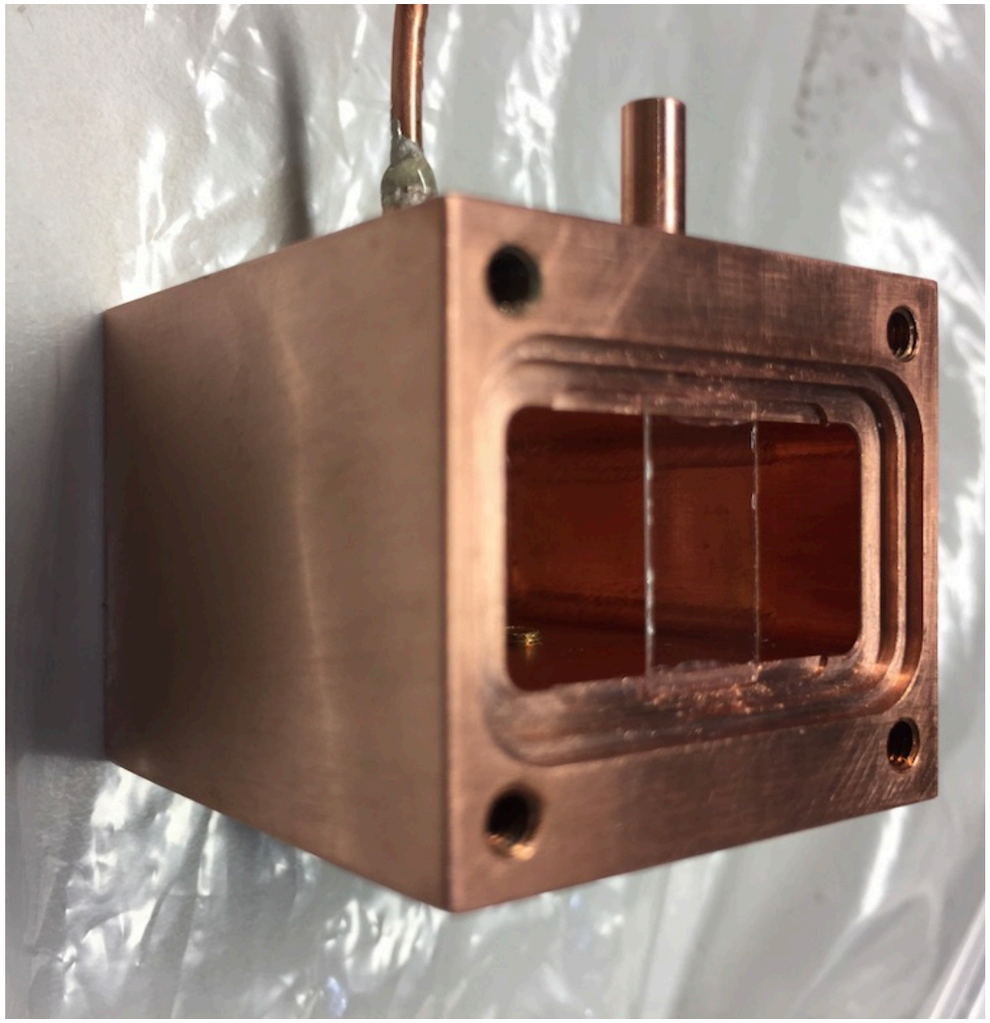
- 3 GrAl resonators
- Sapphire substrate ~1cm² x 300μm
- Assembled in copper holder

RADIOACTIVITY:

- Substrate: target for radioactivity
- Radioactivity creates phonons traveling around
- Phonons reach qubit and break Cooper pairs
- Created quasiparticles spoil coherence

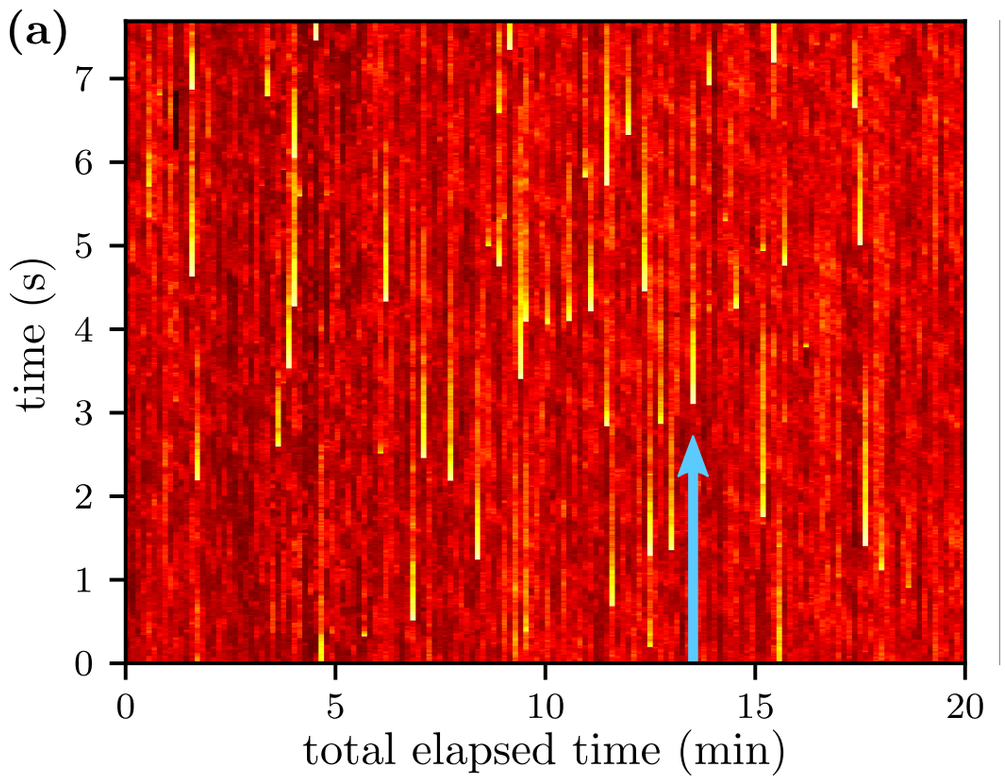
DEMETRA

DEcoherence **M**itigation through **E**nvironmen**T**al **R**adioactivity **A**batement



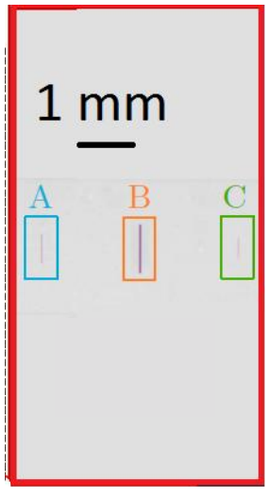
Superconducting resonators deposited on sapphire insulator

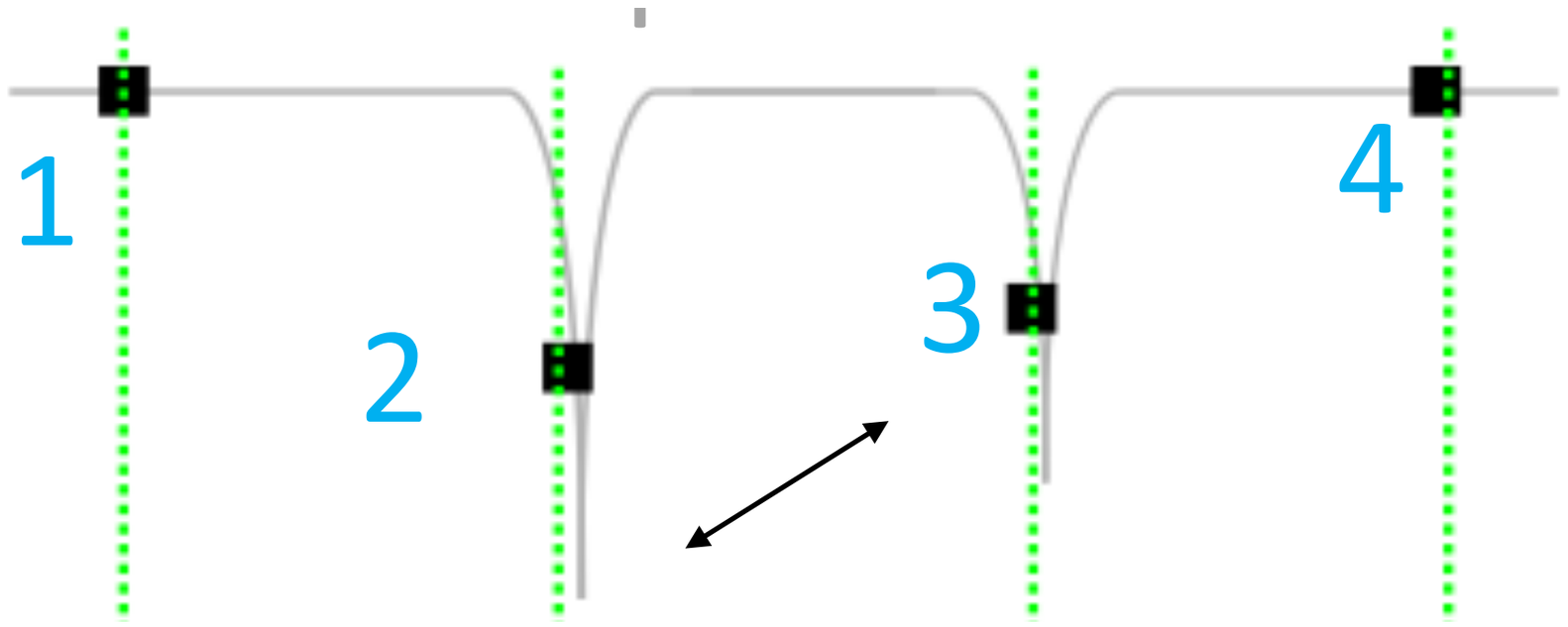
1. **Prove that radioactivity in substrate matter**
2. **Prove that we can suppress their rate**
3. **Understand the impact on qubit coherence**



INTERACTIONS IN SUBSTRATE

- **KIT built a prototype with 3 resonators (good qubit proxy, easy operation)**
- **Operated in LNGS - HallC R&D cryostat with ThO_2 γ-source**
- **Only two of them could be acquired simultaneously**





Credits for these figures/analysis to F.Valenti

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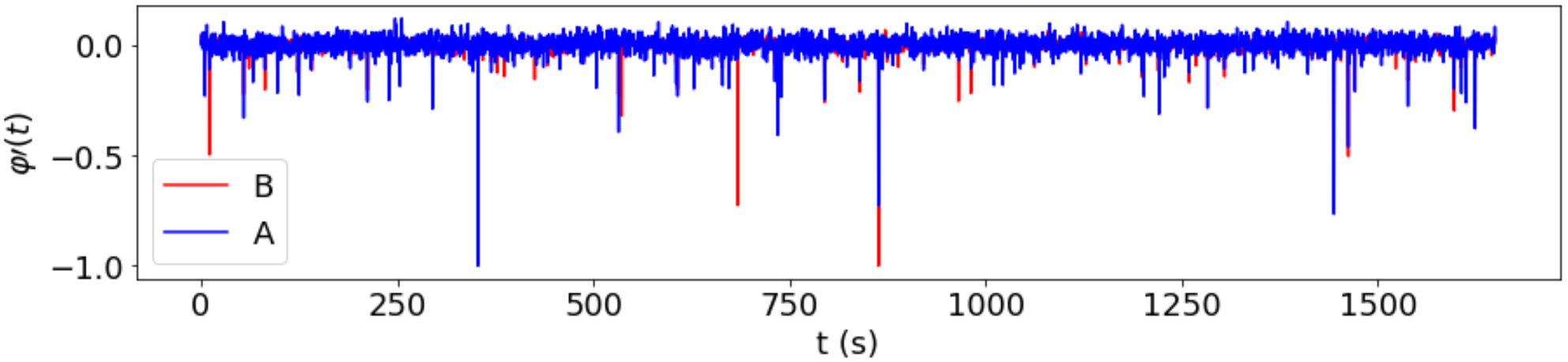

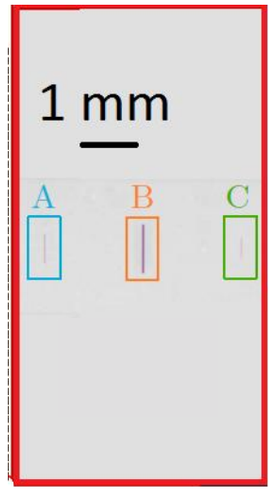

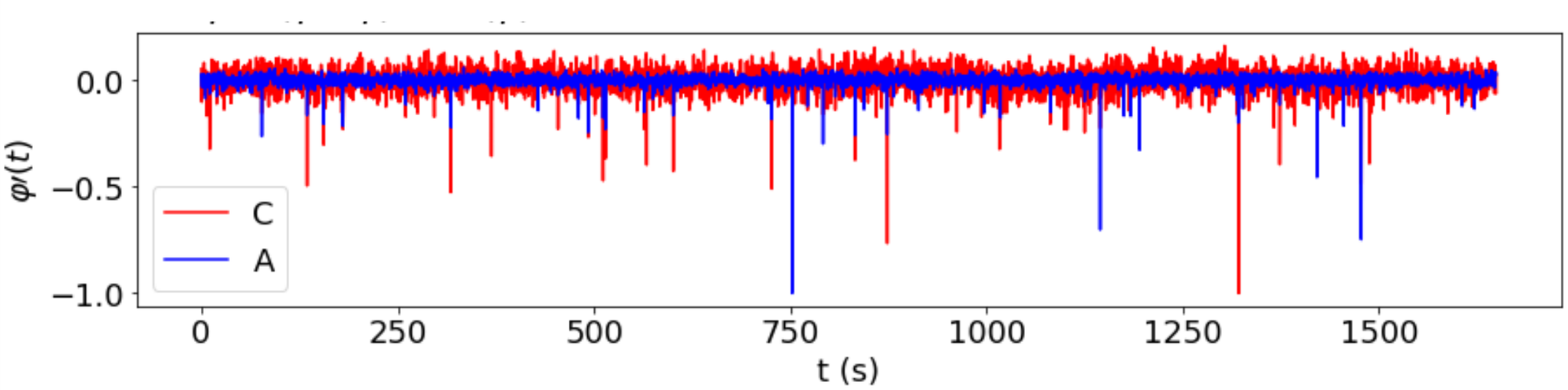

Simultaneous trigger by all resonators —> interactions are in the substrate!

Credits for these figures/analysis to F.Valenti

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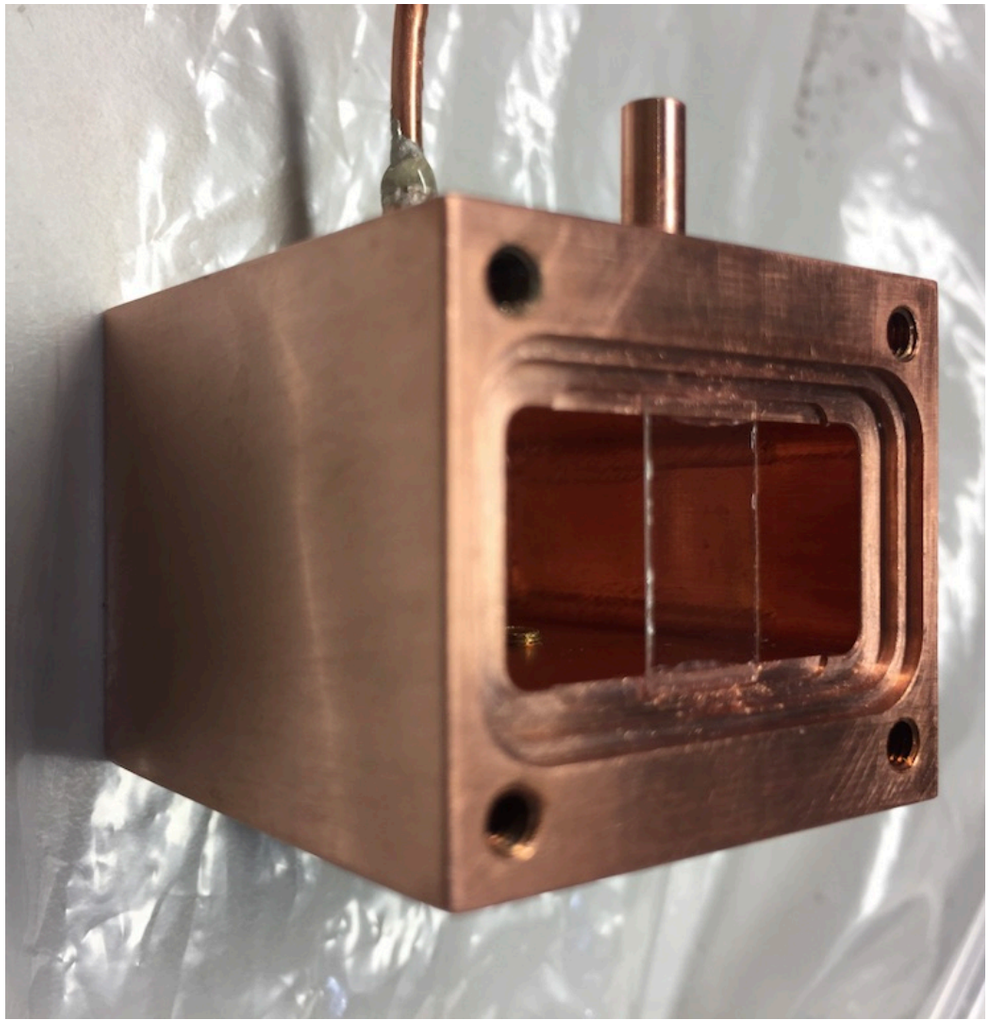

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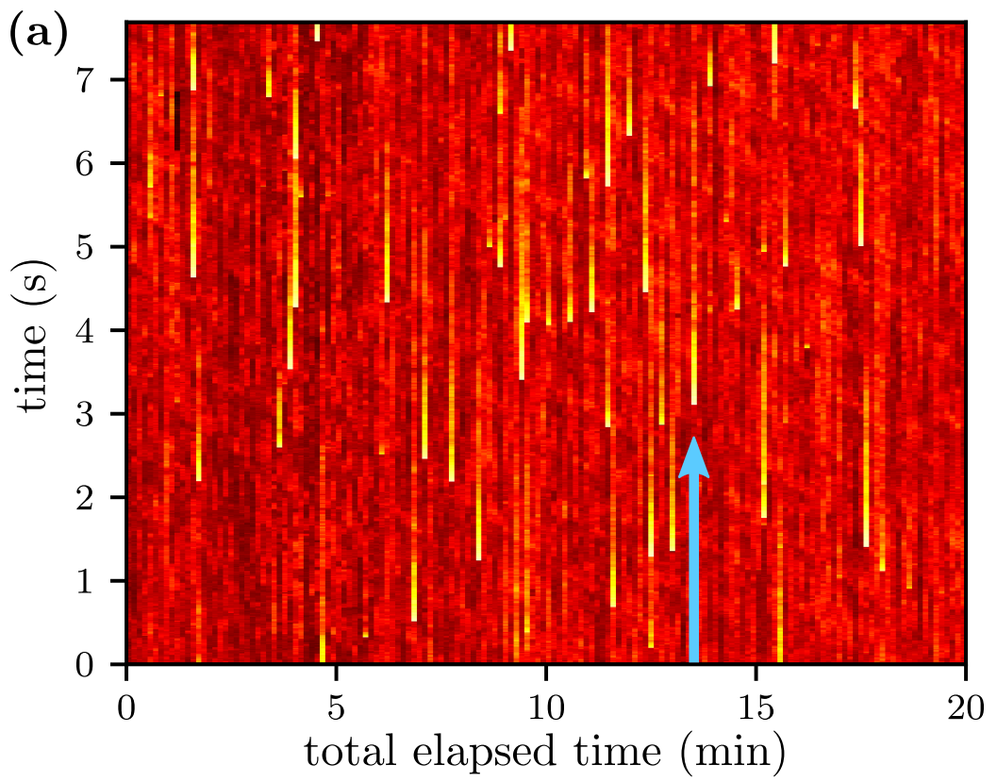
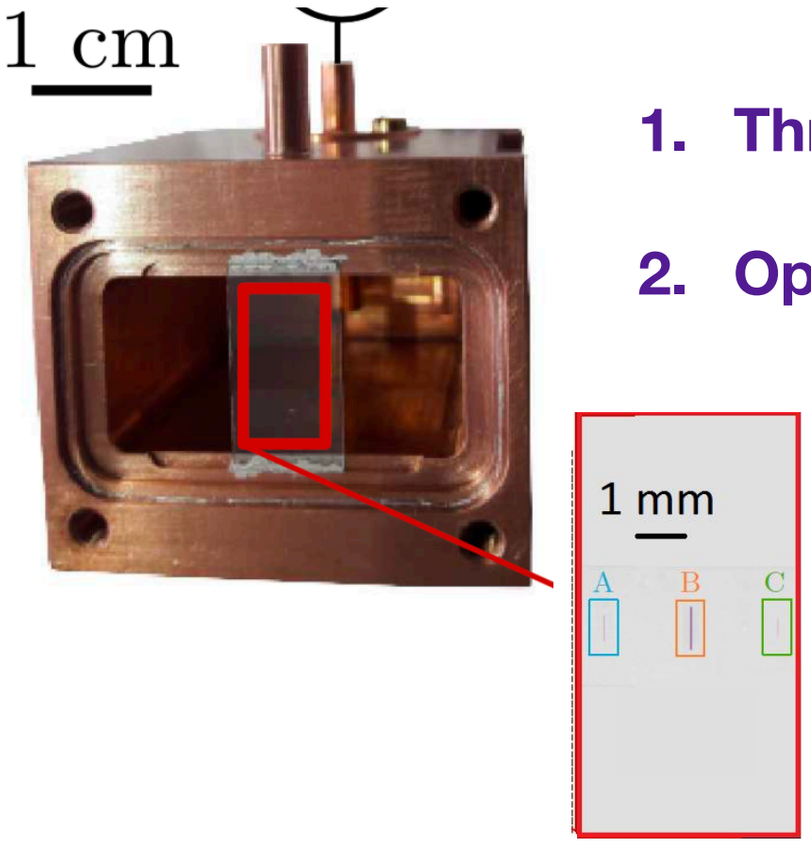
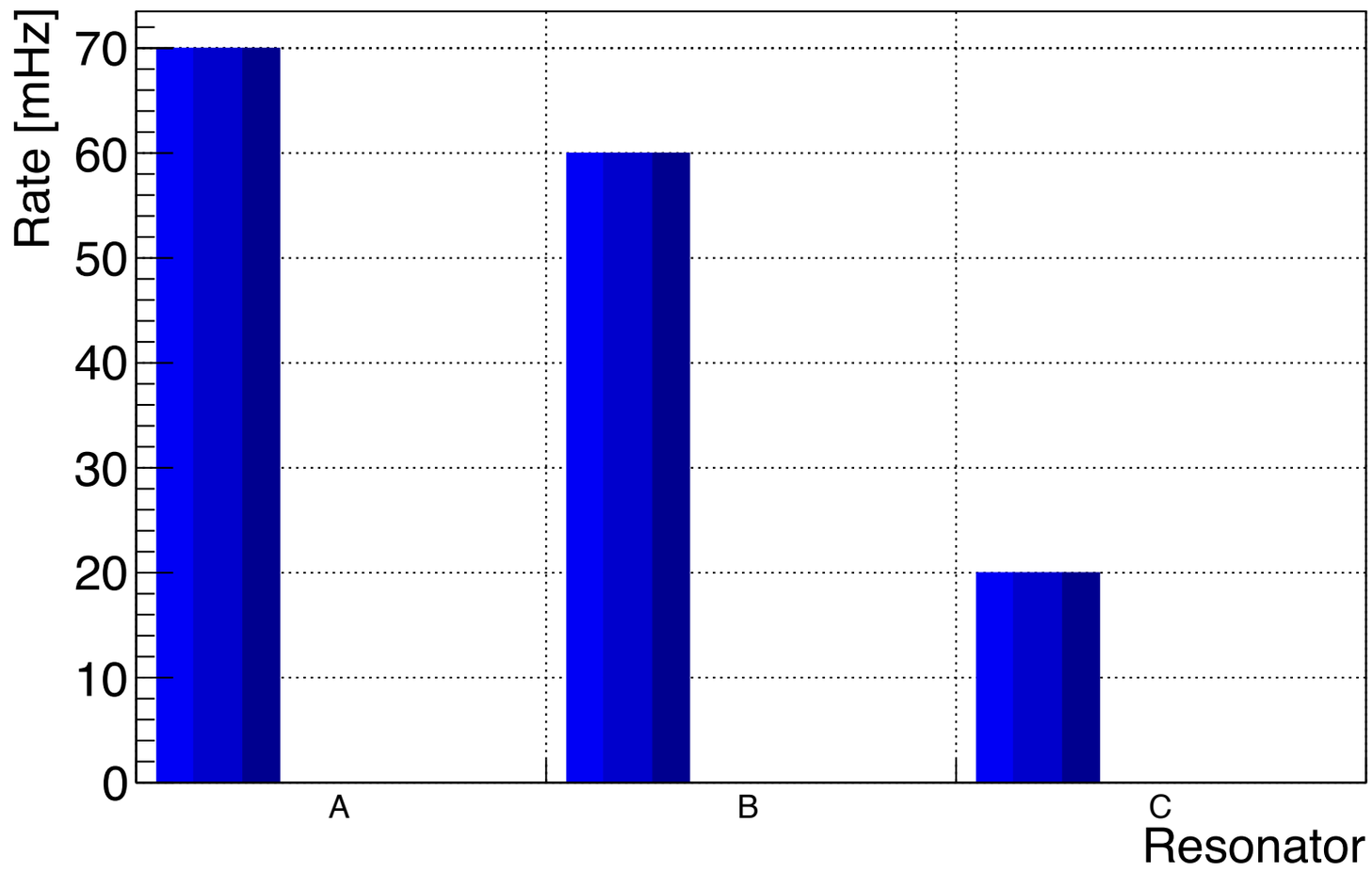


RATE SUPPRESSION



1. **Three resonators assembled with no cleaning protocols**
2. **Operation in a non-shielded cryostat above ground (KIT)**

Different geometries so different sensitivities



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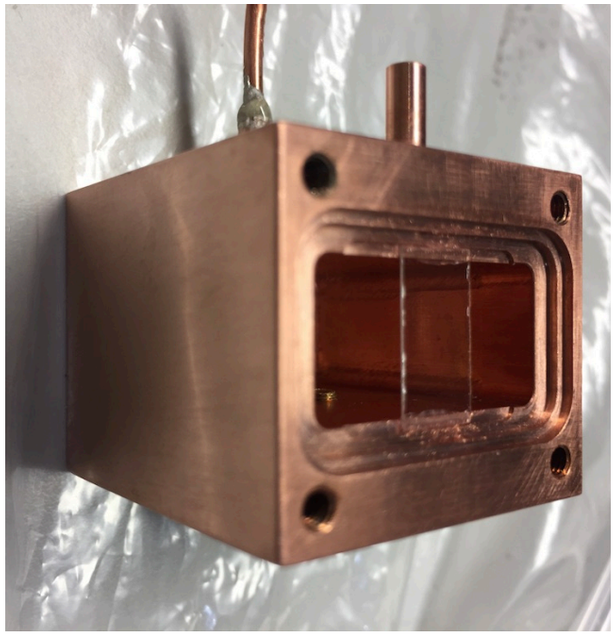
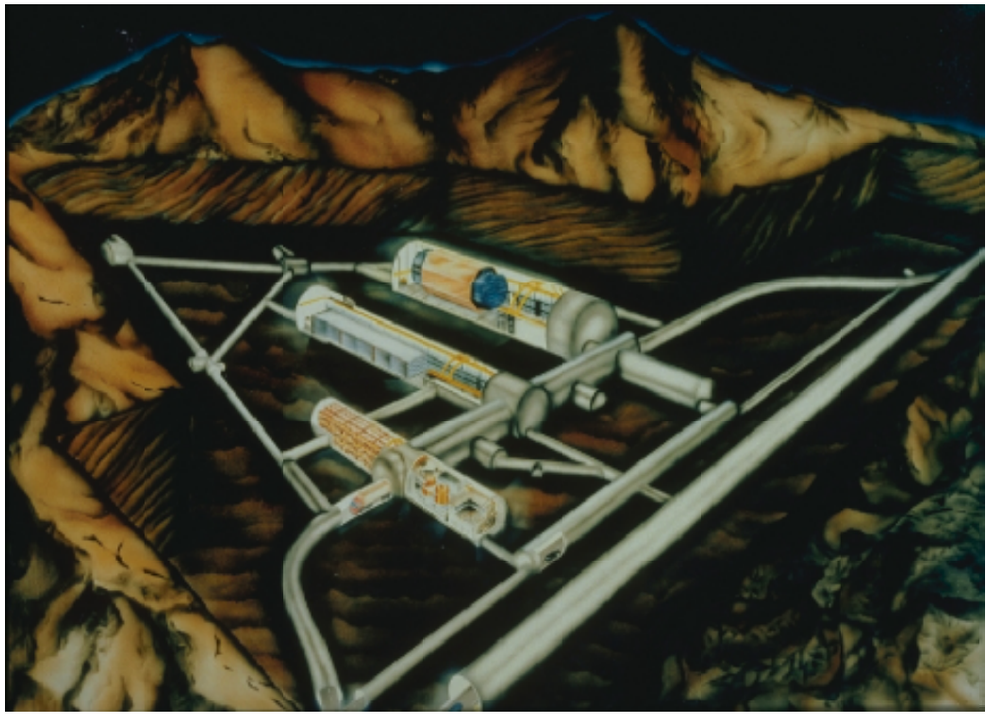


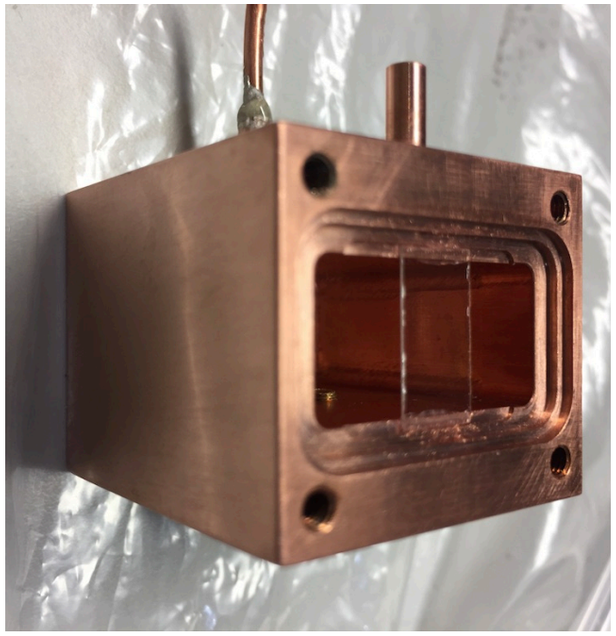
1. **Basic material selection and rough materials cleaning**

2. **Operation underground in and R&D cryostat HallC - LNGS**



Preliminary

RATE SUPPRESSION



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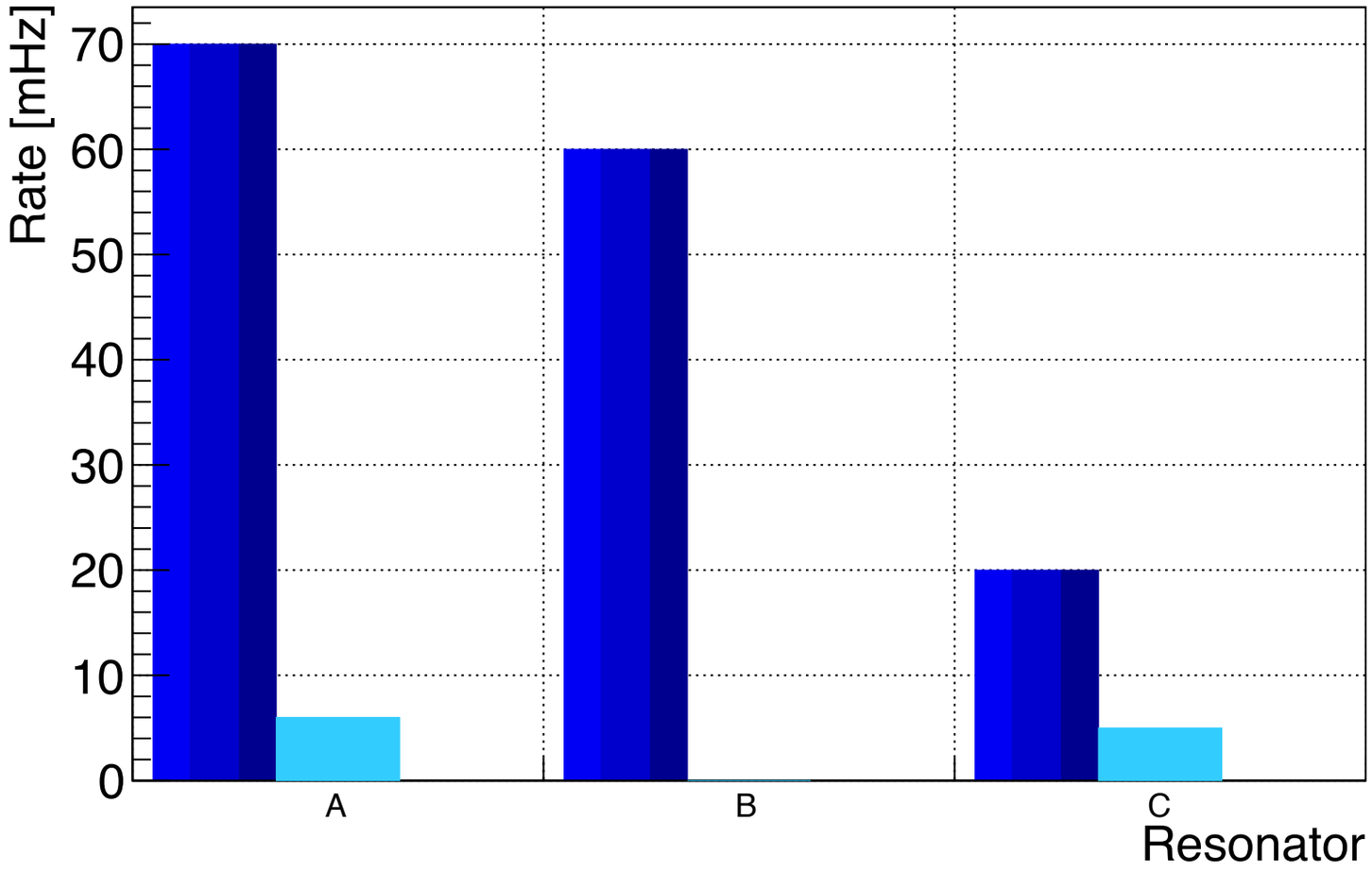
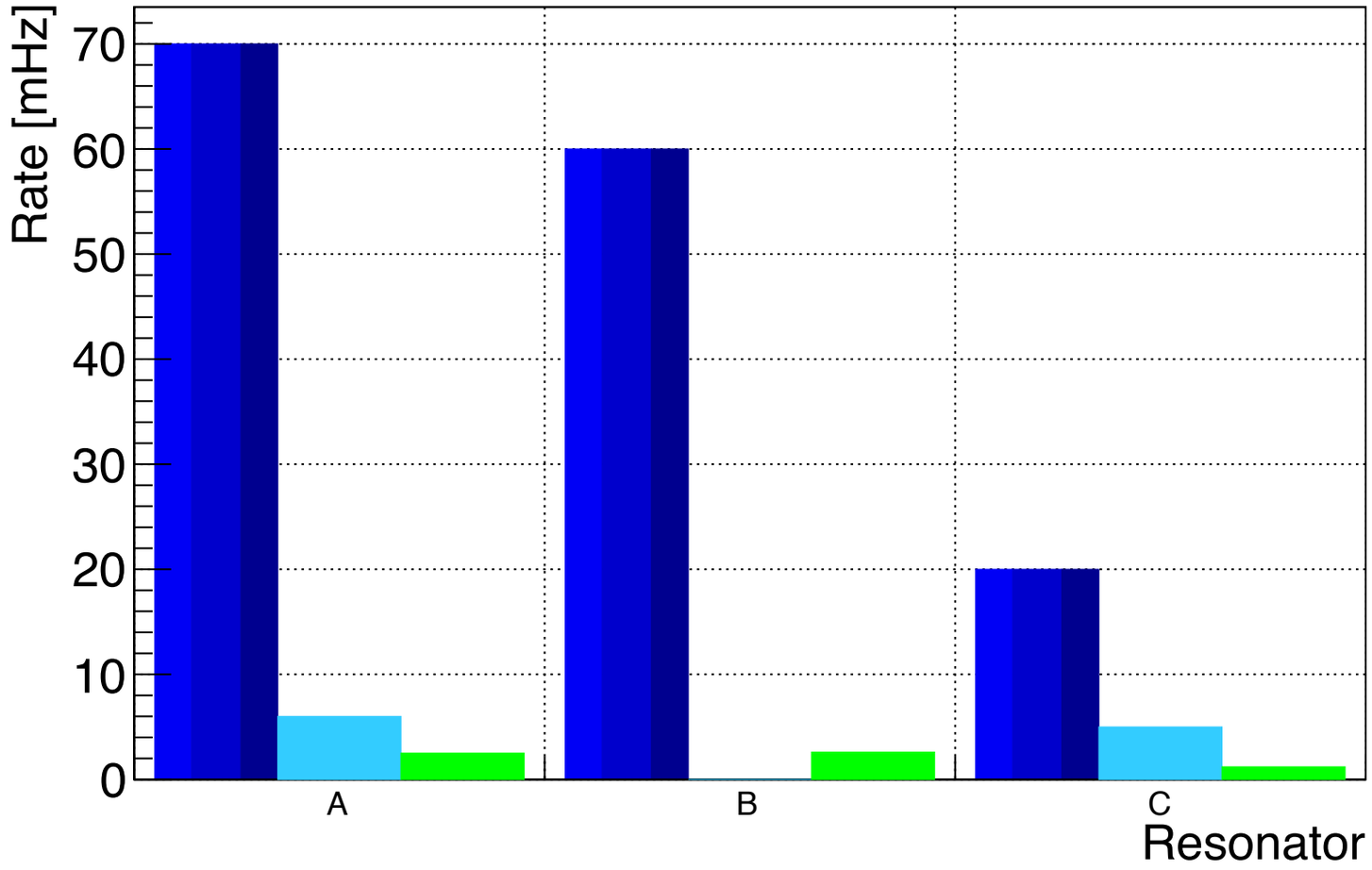


Preliminary

RATE SUPPRESSION

Add a 10-20 cm thick lead shield around the cryostat

Rate drops by more than x10
Milestone for quantum error correction



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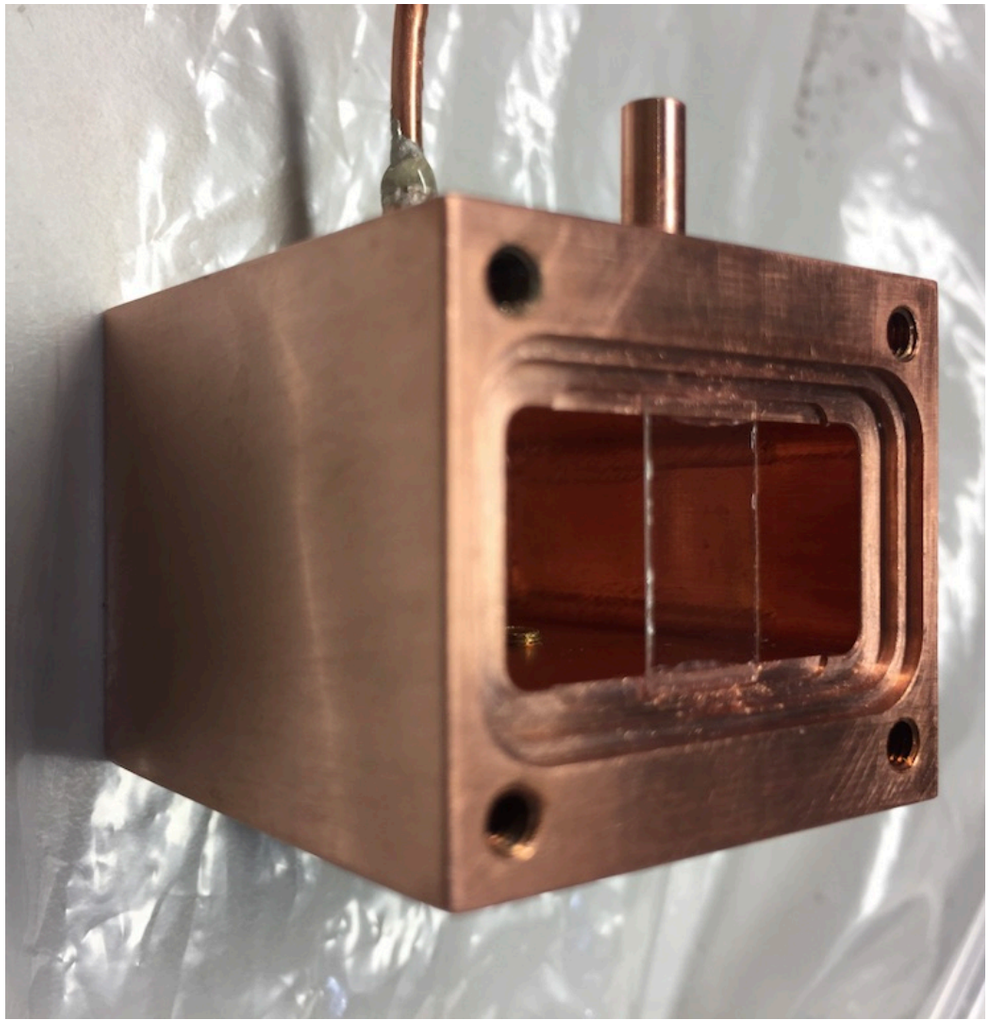

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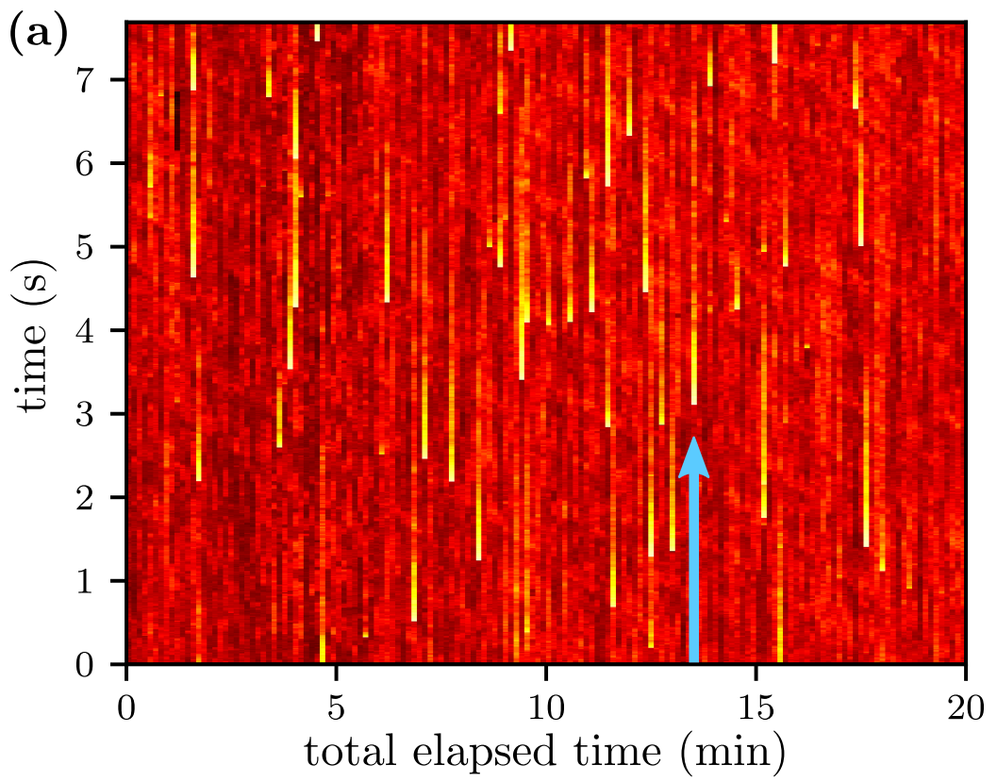
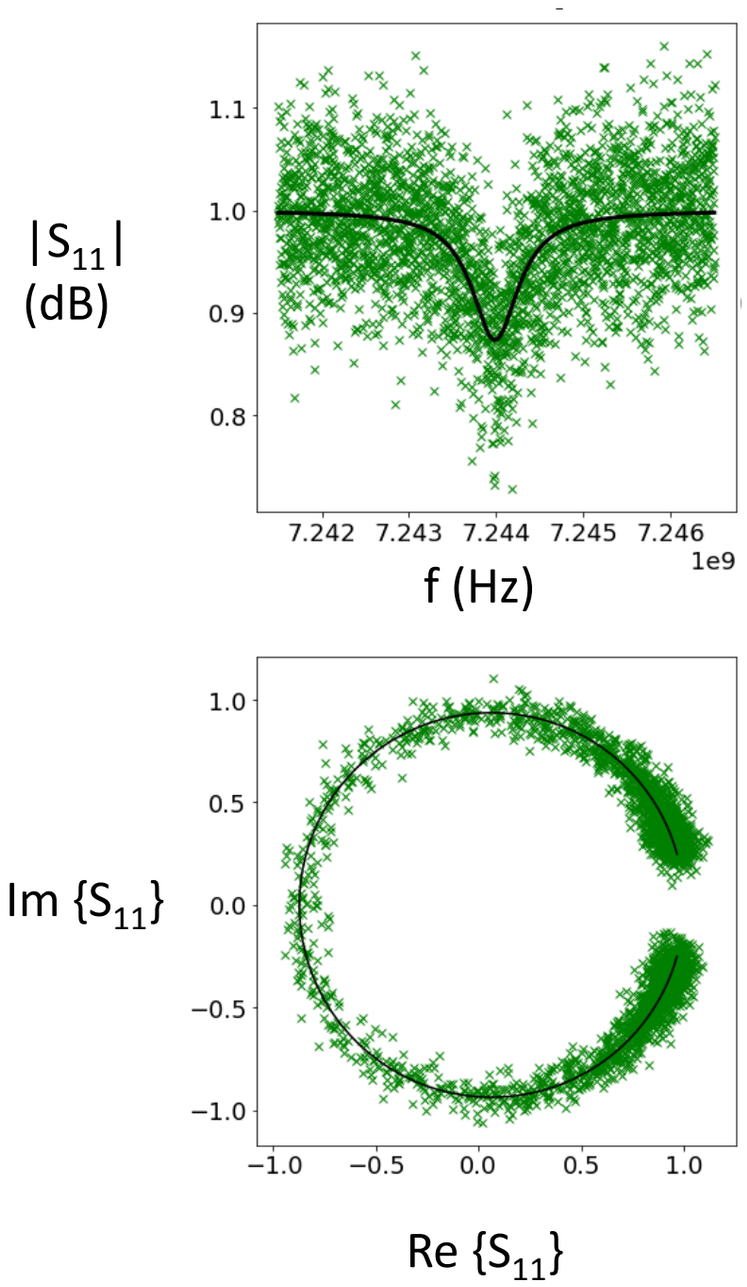
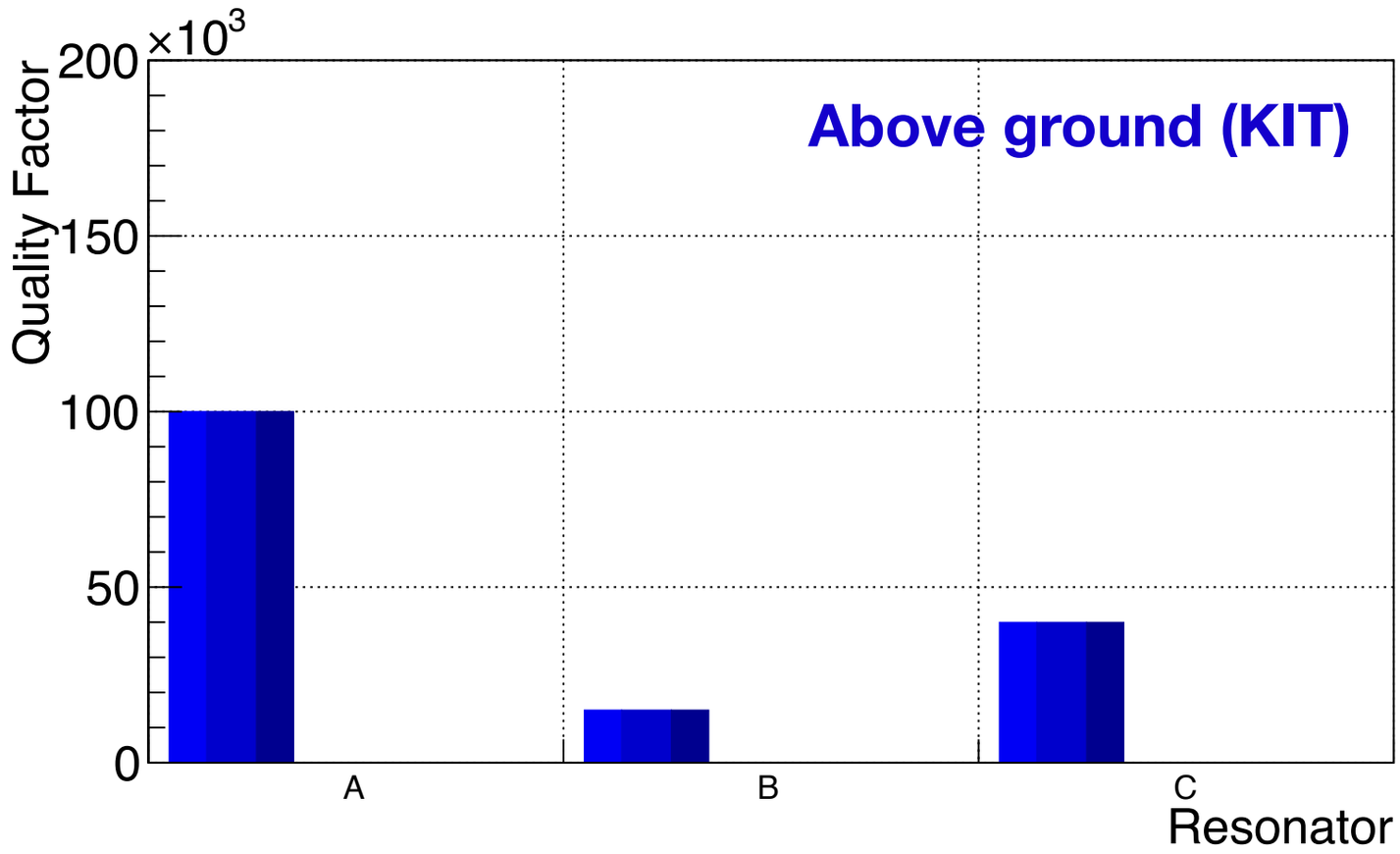


GLOBAL PERFORMANCE vs RATE



Study the internal quality factor: the higher the better



Preliminary

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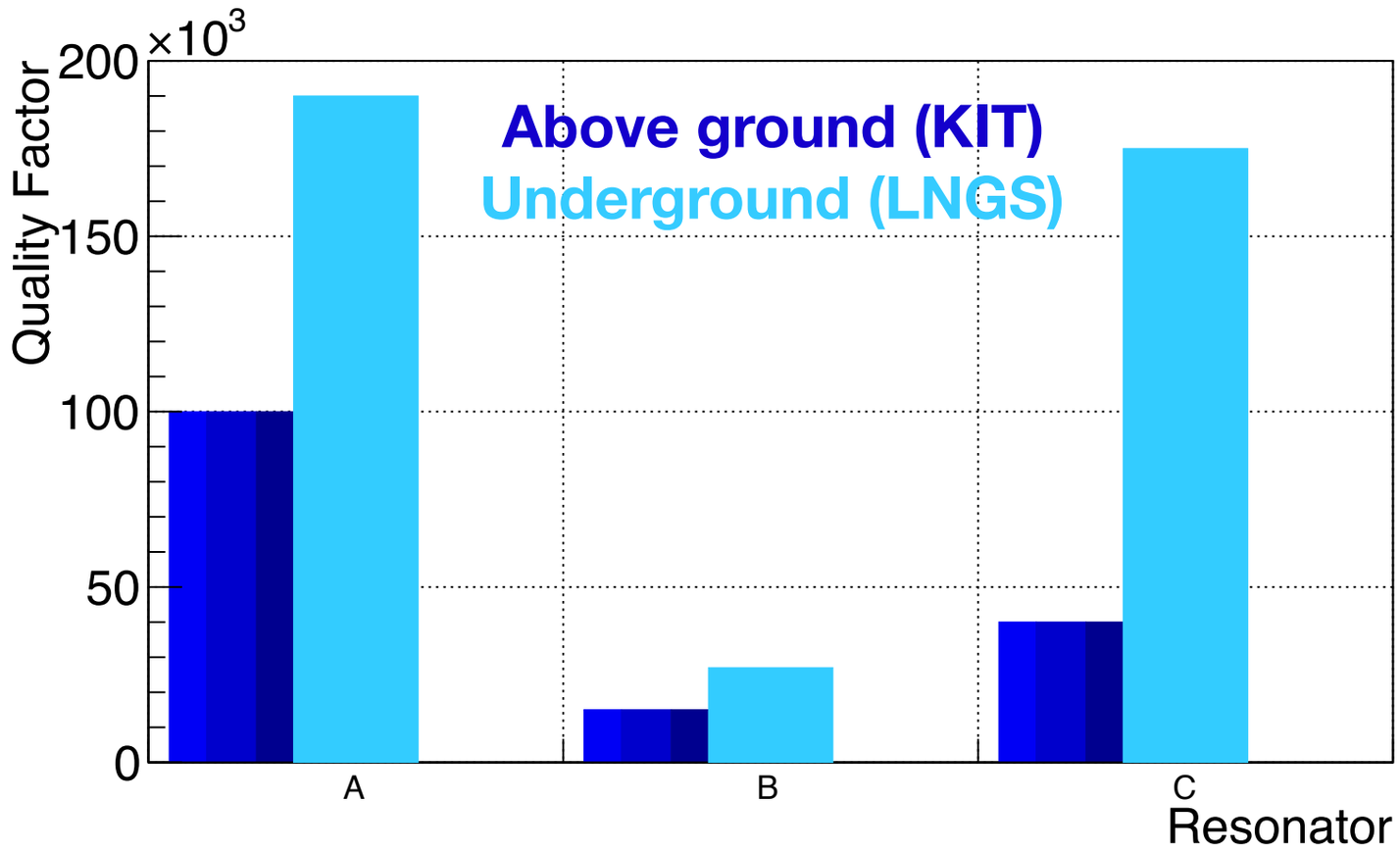
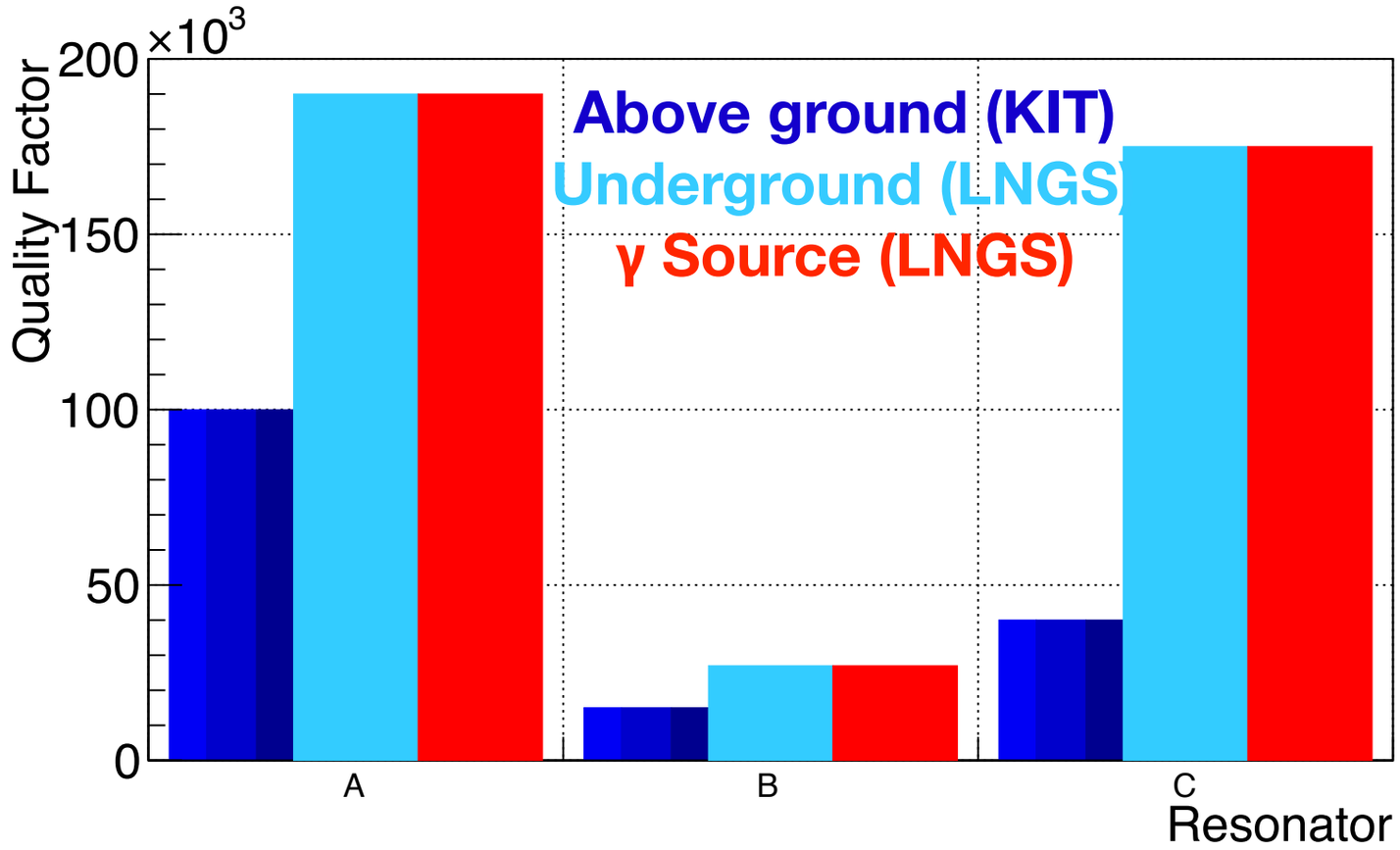


Significant improvement with “clean” set-up

Preliminary

GLOBAL PERFORMANCE vs RATE

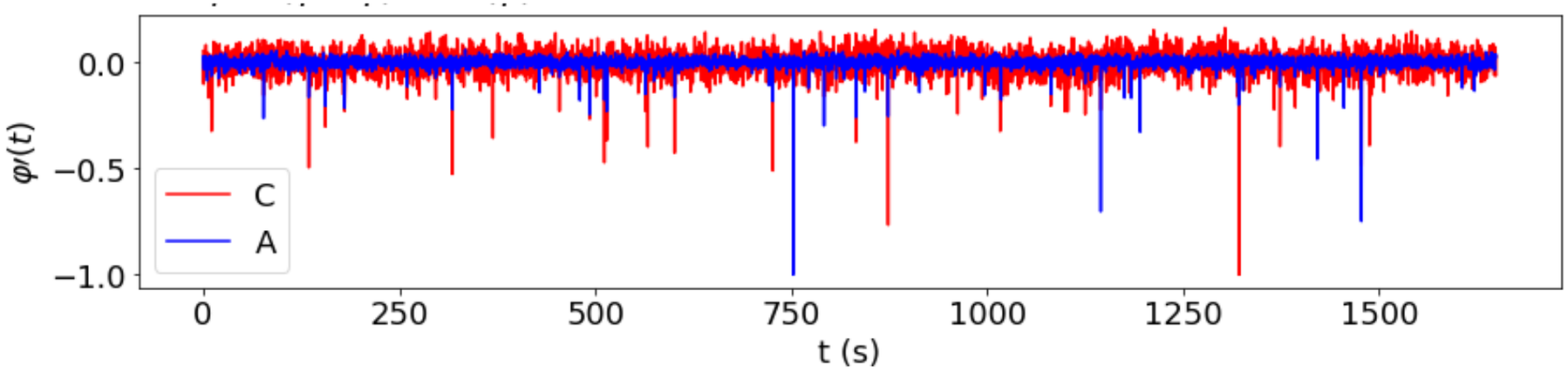
Study the internal quality factor: the higher the better



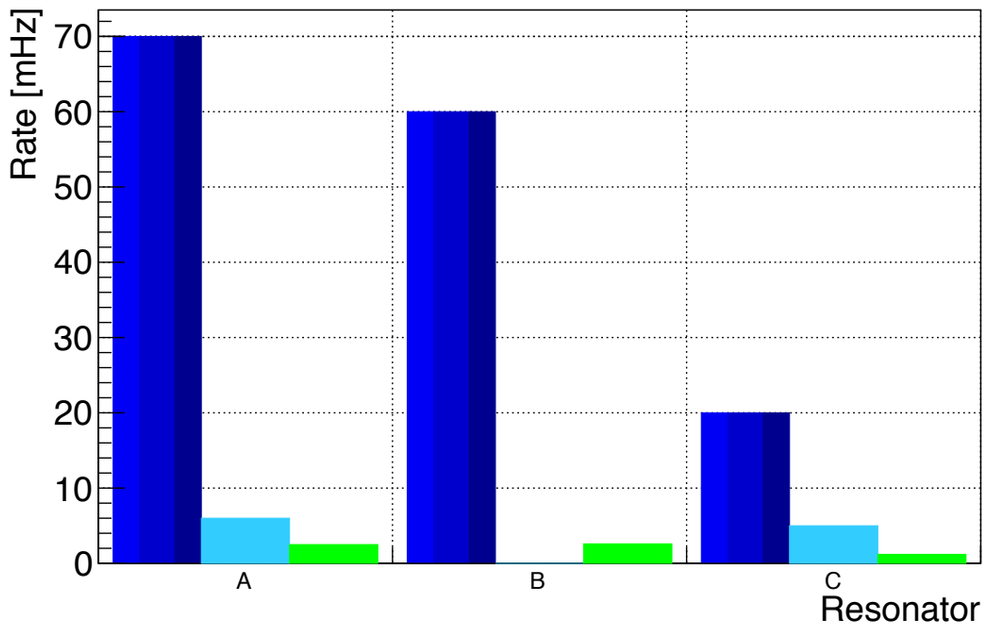
Increasing x100 the rate did not impact the performance!

CONCLUSIONS

1. **Superconducting qubits can be sensitive to interactions in substrate**



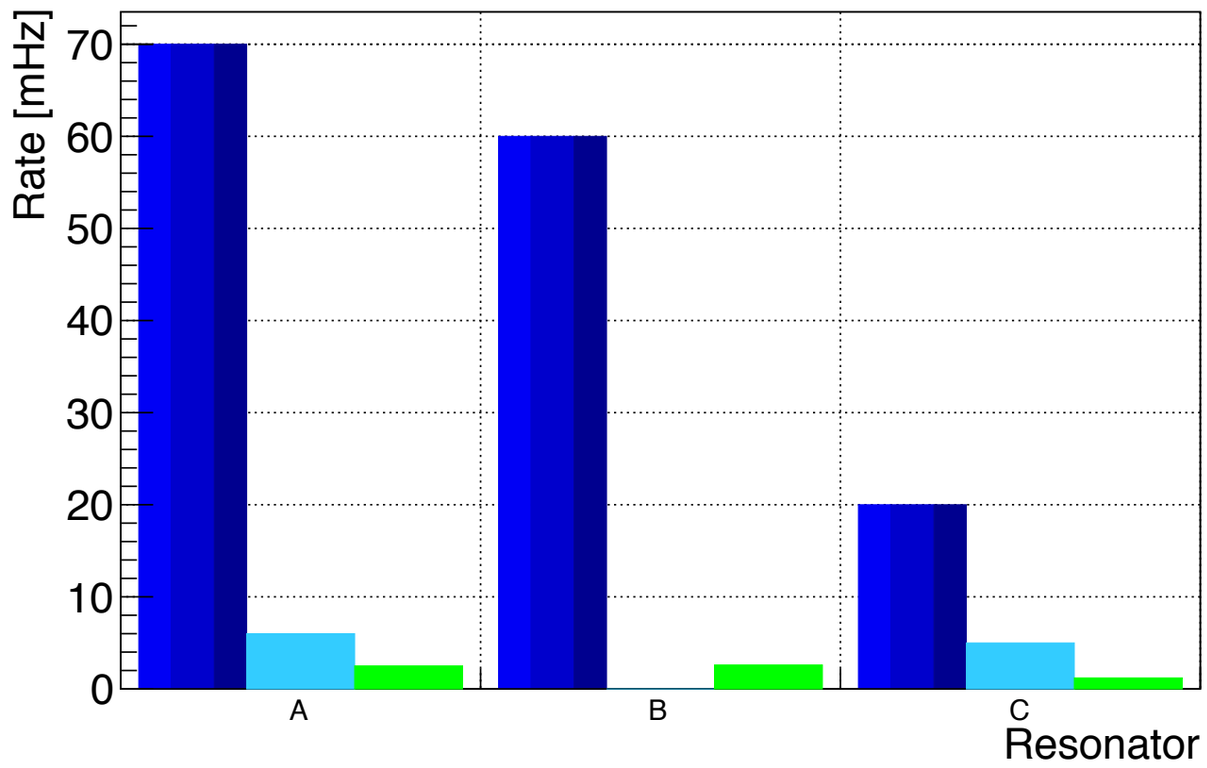
2. **Proved that it is possible to suppress them**



PERSPECTIVES

1. **Separate single contributions to the measured rate (cosmic rays, materials…)**

   - **Radio-assay**
   - **Simulations**



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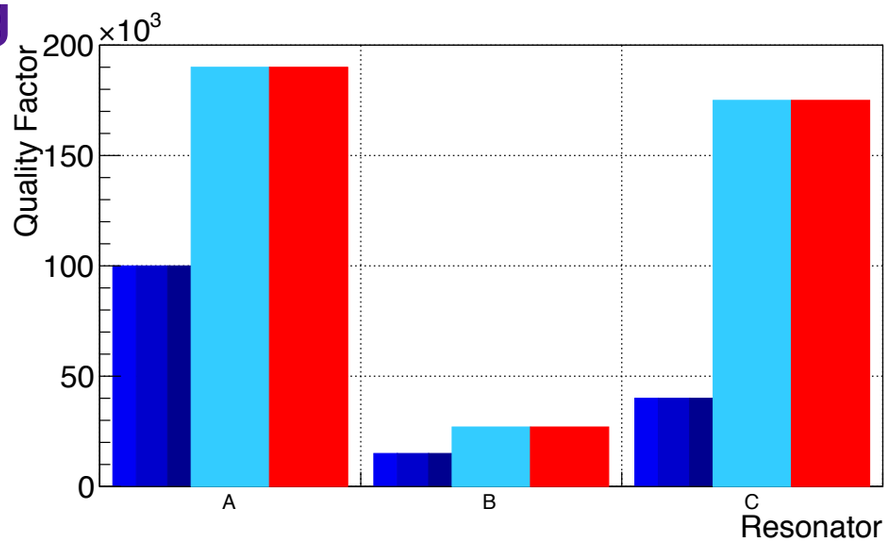
   - **Why adding a source did not result in a worsening**



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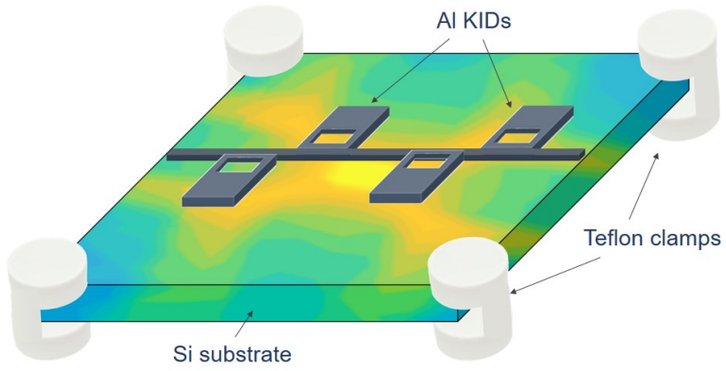
2. **Understand “impacts rate” vs “general performances”:**
   - **What determined a general improvement**
   - **Why adding a source did not result in a worsening**
3. **Which Physics relates radioactivity to coherence?**
   - **Simulate phonos propagation and absorption**
   - **Theoretical framework phonons <—> quasiparticles**



M. Martinez et al.
Phys Rev Apply 2019

THANKS FOR THE ATTENTION!

V. Caracciolo, L. Cardani, N. Casali, M. Clemenza, A. Cruciani, L. Gironi, S. Pirro, C. Rusconi, M. Vignati

I. Colantoni

M. Martinez

T. Charpentier, L. Gruenhaupt, D. Gusenkova, F. Henriques, M. Lagoin, I. Pop, F. Valenti, W. Wernsdorfer, A. Ustinov

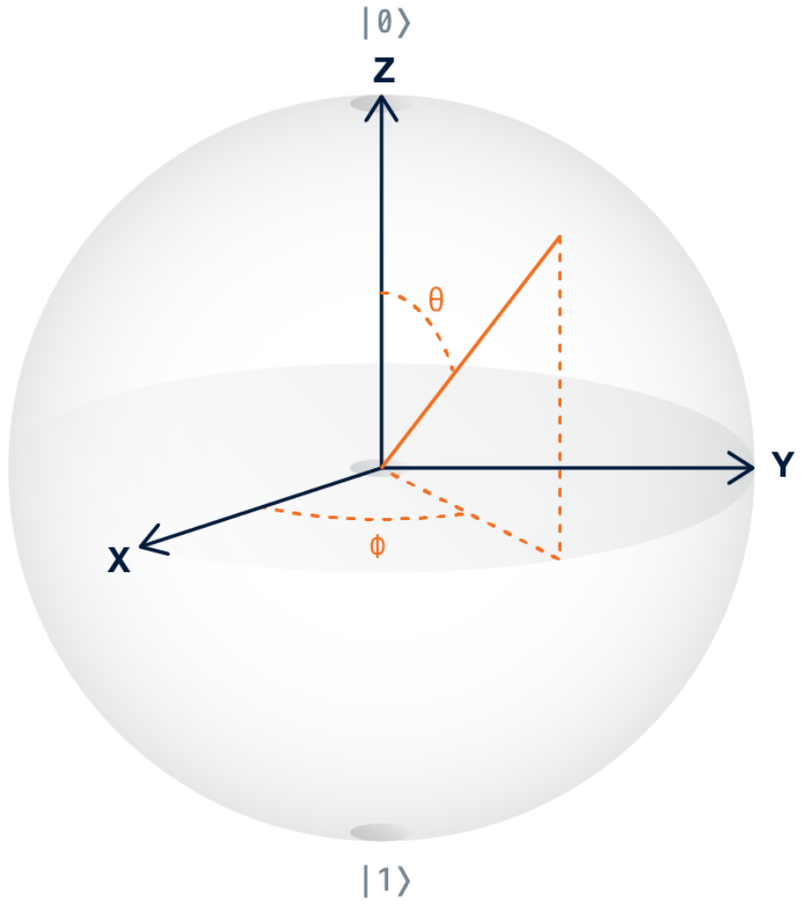
G. Catelani

We welcome new collaborators!

QUANTUM BITS

Fundamental unit of information in a quantum computer
***Any* two level quantum system**

$$\alpha\,|0\rangle + \beta\,|1\rangle$$



Key feature: entanglement

$$\Psi = \sum_{s_1,\ldots,s_N} \alpha_{s_1,..,s_N}\psi_{s_1,..,s_N}$$

Quantum computer with n qubits: 2^n-1 complex numbers
Classical memory with n bits: string of n zeroes and ones

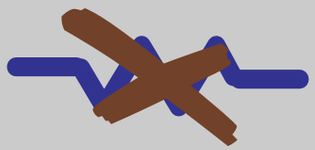
BUILDING SUPERCONDUCTING QUBITS

Macroscopic electrical circuit

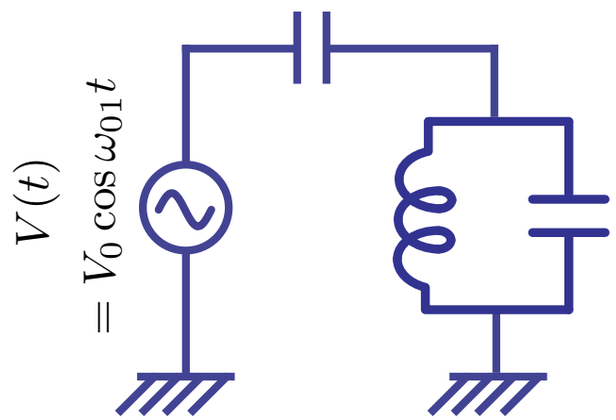
Standard toolkit

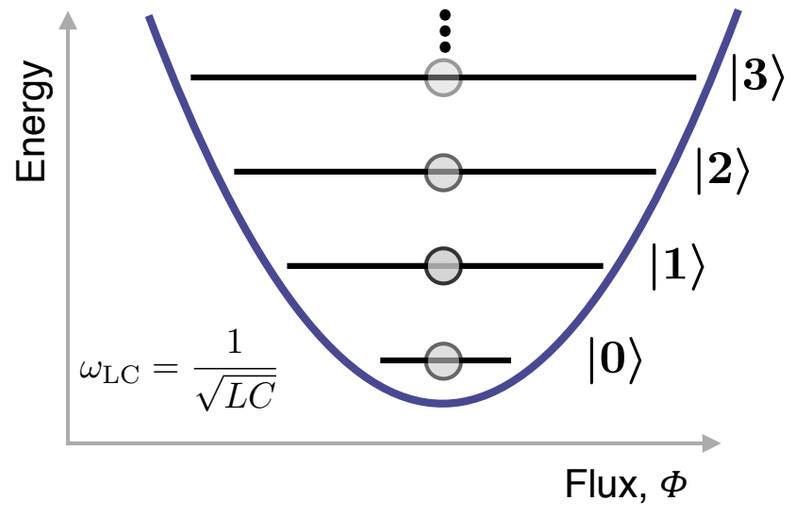
Capacitor (C)

Inductor (L)



Resistor (R)





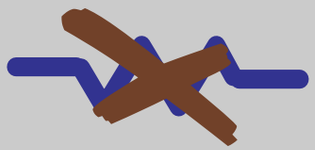
BUILDING SUPERCONDUCTING QUBITS

Quite simple to design and fabricate

Standard toolkit

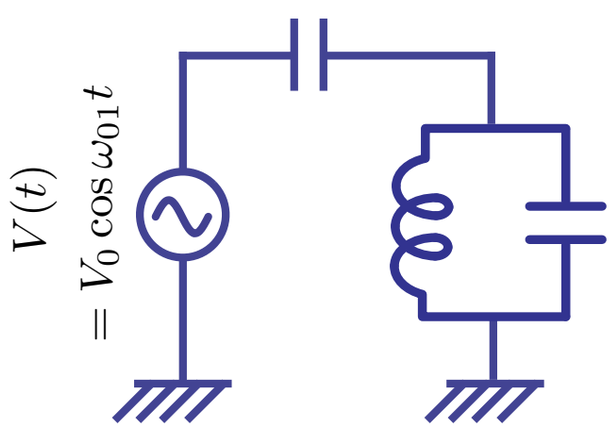
Capacitor (C)

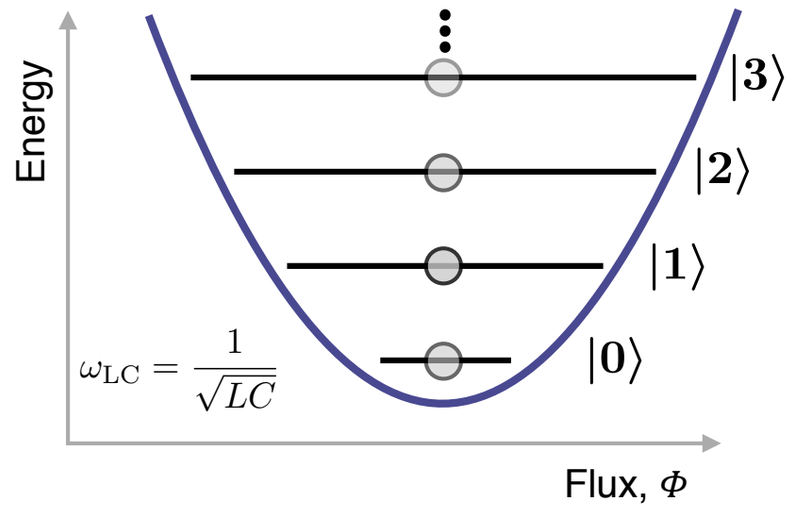
Inductor (L)

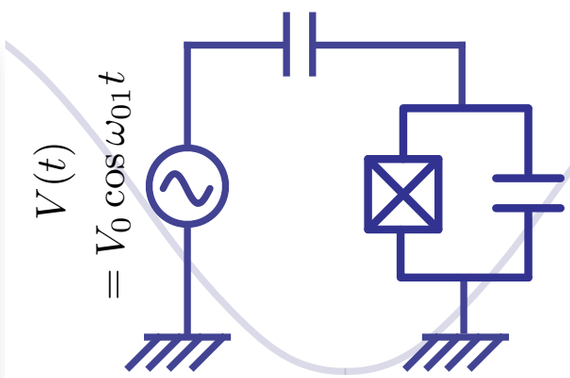


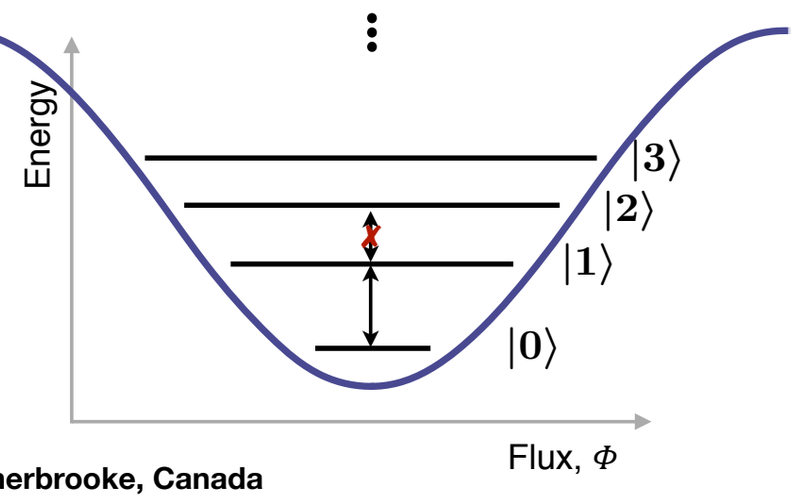
Resistor (R)

Josephson junctions









Credits for the figures to A. Blais, Université de Sherbrooke, Canada

THE NIGHTMARE OF QUASI-PARTICLES IN QUBITS

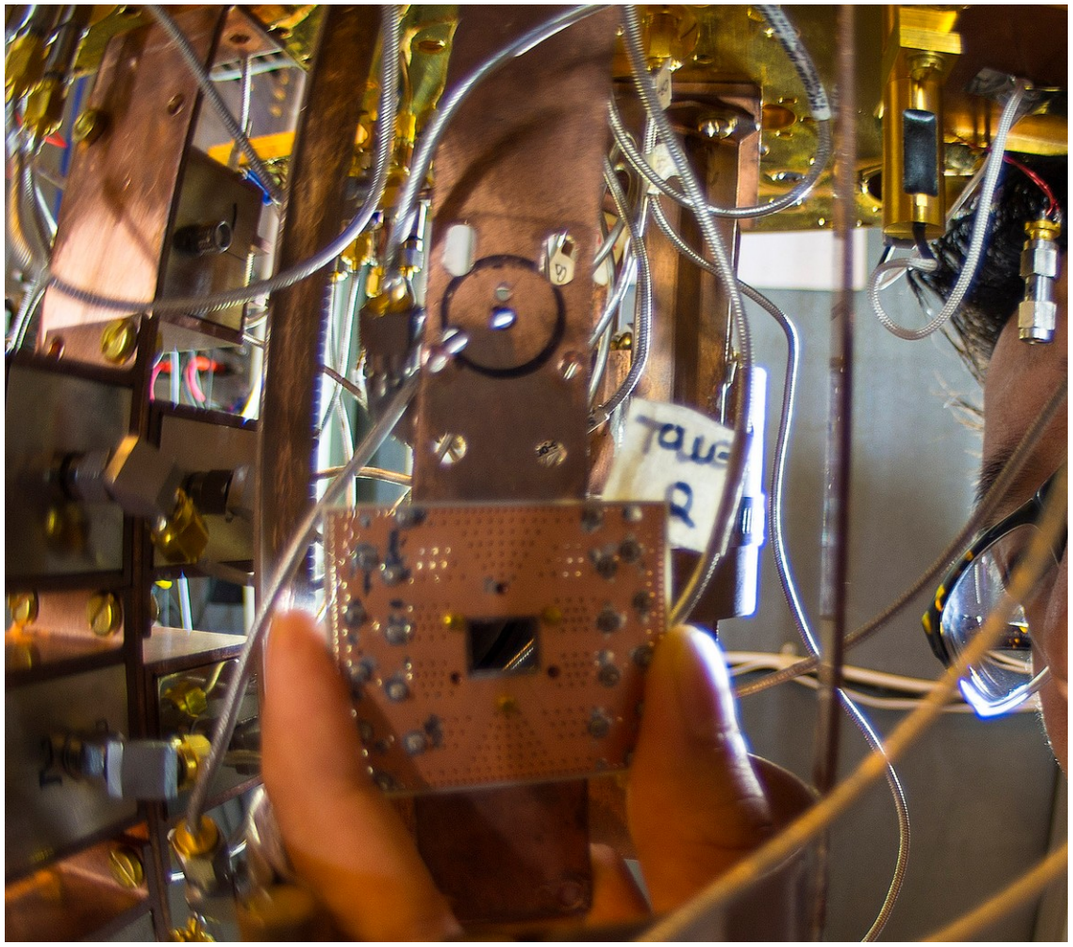
Superconductor cooled to mK temperature —> electrons bound in Cooper pairs
BUT
Many mechanisms can break Cooper pairs, producing quasiparticles

PROBLEM

- **Absorb qubit energy and dissipate it via phonons**
- **Excite the qubit to |1> level**
- **Change the ΔE between |0> and |1>**
- **....**

PRODUCTION OF QUASI-PARTICLES IN QUBITS

What is the origin of quasiparticles bursts?
How will they impact the performance of qubits?

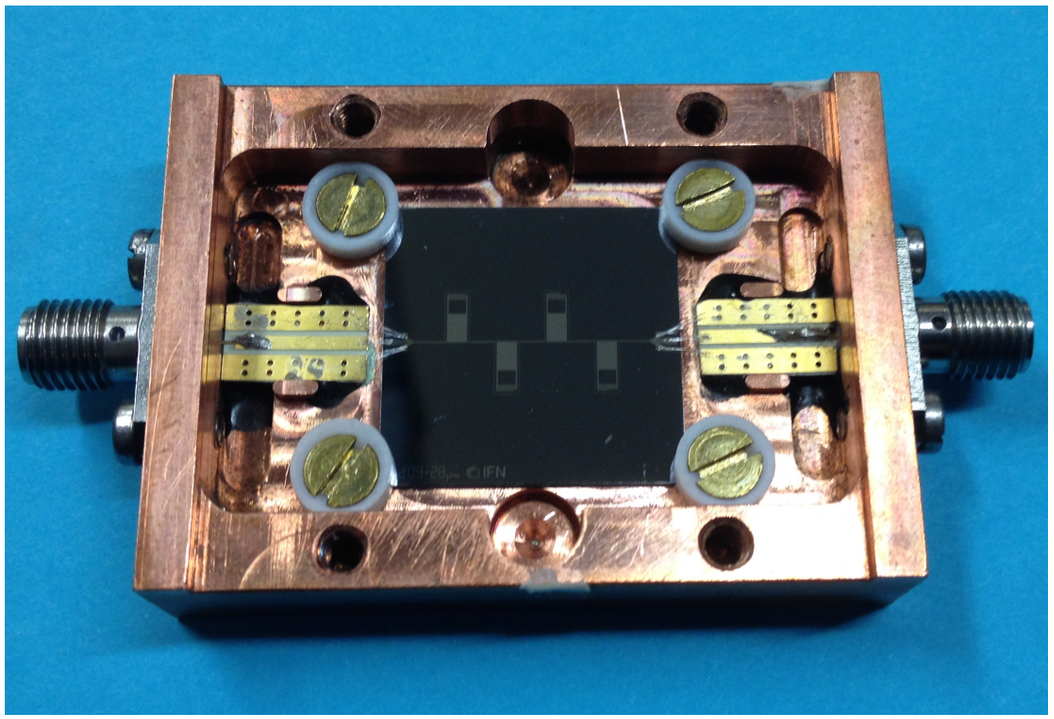


HOW

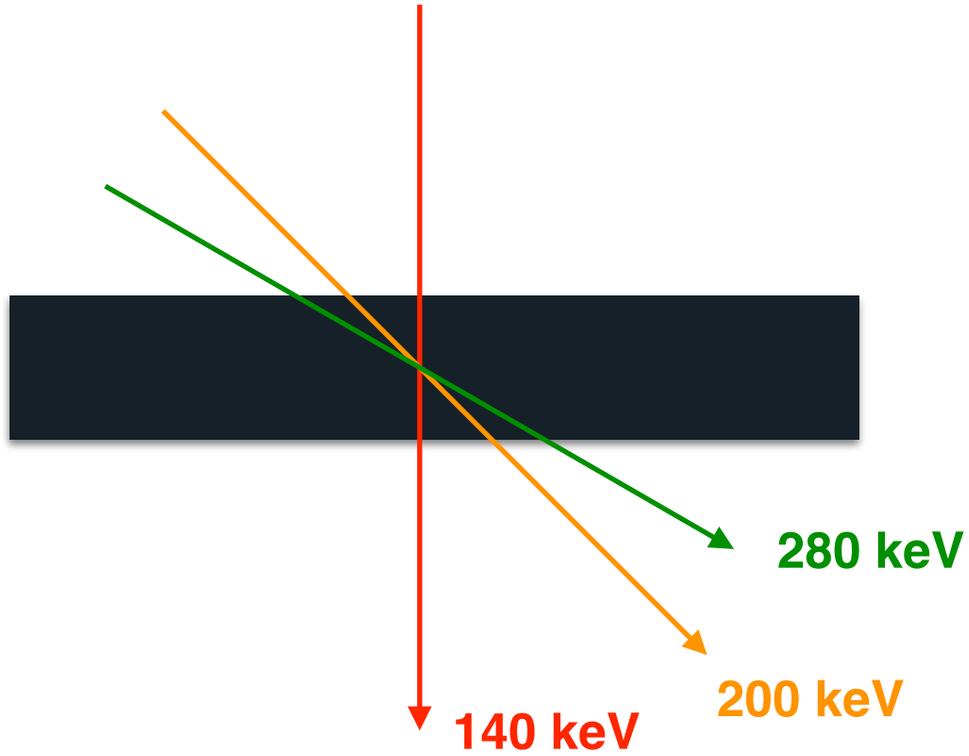
- **Infrared radiation**
- **Thermal stress**
- **Dissipation of the readout line**
- **....**
- **Phonons**

QUBITS vs RESONATORS

In qubit, phonons are a nightmare
On the contrary, in Particle Physics, phonons are what we want to measure!The technologies have opposite requirements but can benefit from each others

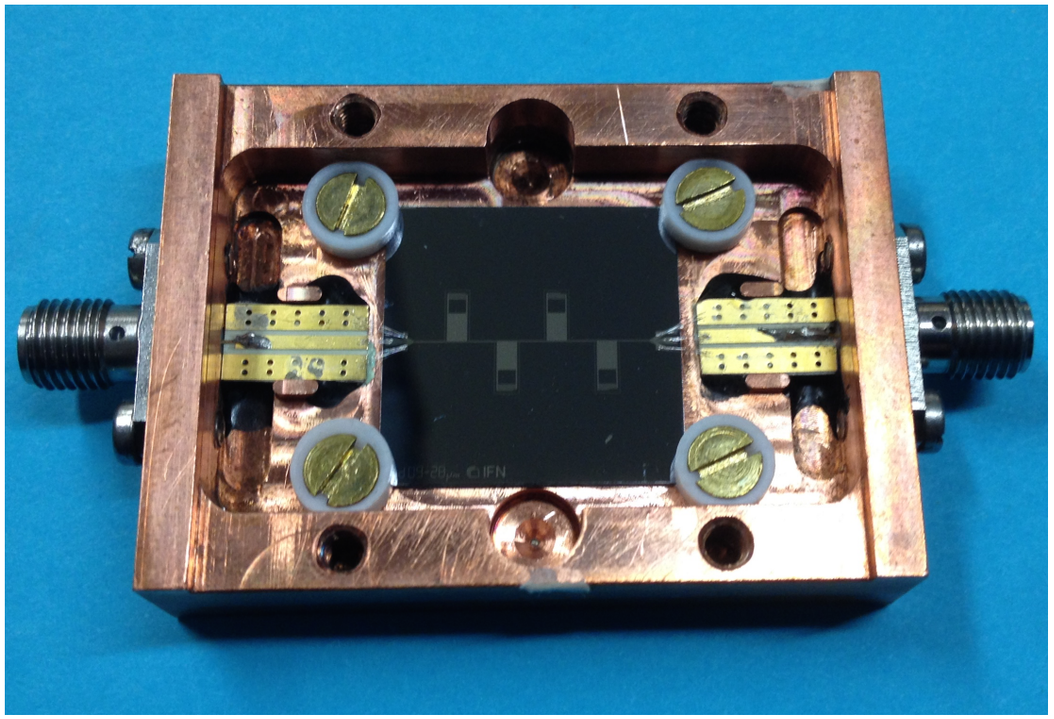


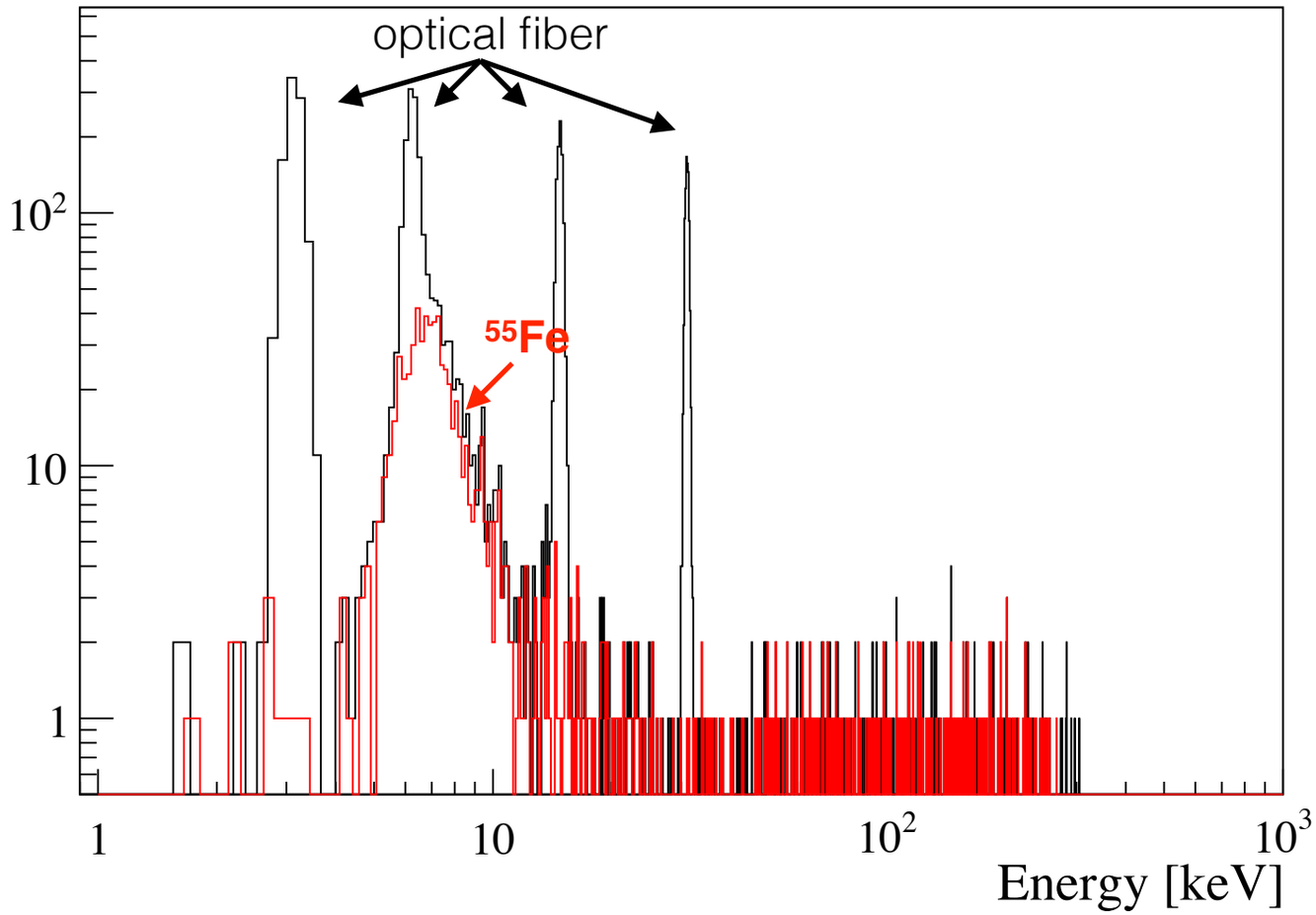
KID (Kinetic Inductance Detector)
Developed within the CALDER project
(ERC starting grant, PI: M. Vignati)



~ 4 μ/min with an E 150-300 keV

QUBITS vs RESONATORS





Flat distribution from a few keV to ~300 keV (above detector not working)

Rate (>10 keV) = 30 events/min detector