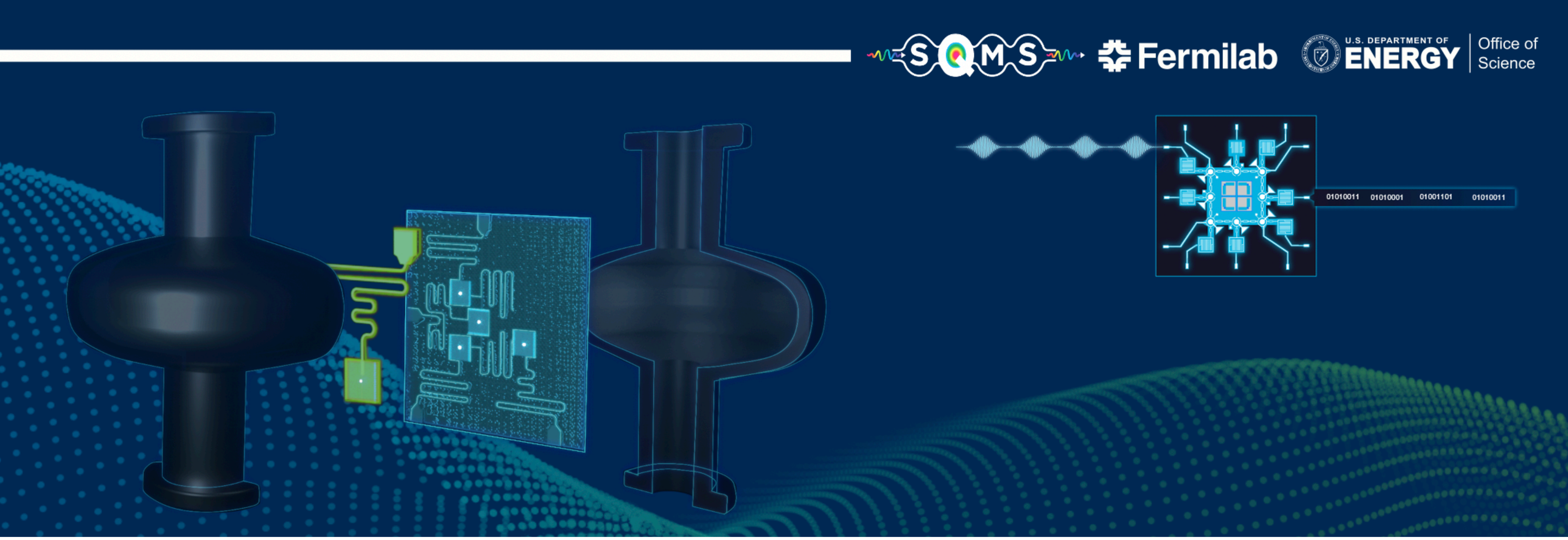


Underground measurements

Laura Cardani et al.
15/10/2021

(Most) Involved People

L. Cardani

N. Casali

I. Colantoni (CNR)

A. Cruciani

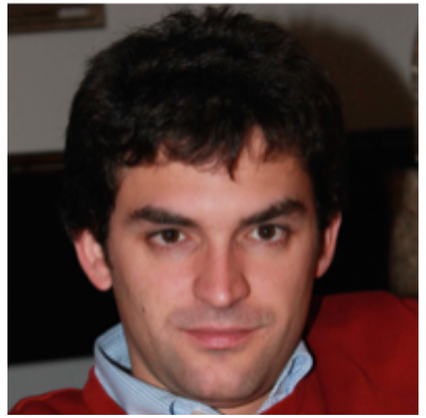
F. De Dominicis (GSSI)

G. D'Imperio

C. Tomei

V. Pettinacci

S. Pirro (LNGS)



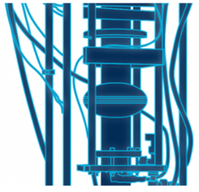
M. Vignati (Sapienza)

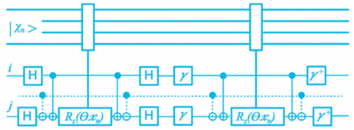
+ precious support from M. Junker as technical coordinator of the LNGS Facility, M. Laubernstein and L. Pagnanini (LNGS), L. Gironi, M. Nastasi (MiB) for radioactivity measurements.

SQMS Deliverables

Focus Area	Major Activity	Deliverables and Benchmarks	Center Year				
			1	2	3	4	5
Materials for 2D and 3D Quantum Devices	(1) Infrastructure & Testbeds *Impacts: (2), (3), (4), (5),*	Infrastructure upgrades to enable low (T~1.5K) and ultralow (T<=100mK) temperature characterization stations at partner institutions **Risk mitigation: risk reduction via creation of additional testing bandwidth to evaluate new ideas*	■				
		SRF cavity-based testbed available for characterizing dielectrics in quantum regime at Fermilab	■	■	■	■	■
		SRF cavity-based testbed available for characterizing dielectrics in the quantum regime at Northwestern and NIST/UColorado		■	■	■	■
	(2) Advanced Materials Studies *Impacts: (4), (5)* *Drives: (1)*	Initial exploration of dominant quasiparticle sources including underground measurements (INFN) of the 2D Rigetti transmon **Risk mitigation: by testing the same devices in different testbeds by different experimenters, environments and techniques that maximize performance can be identified*	■	■			

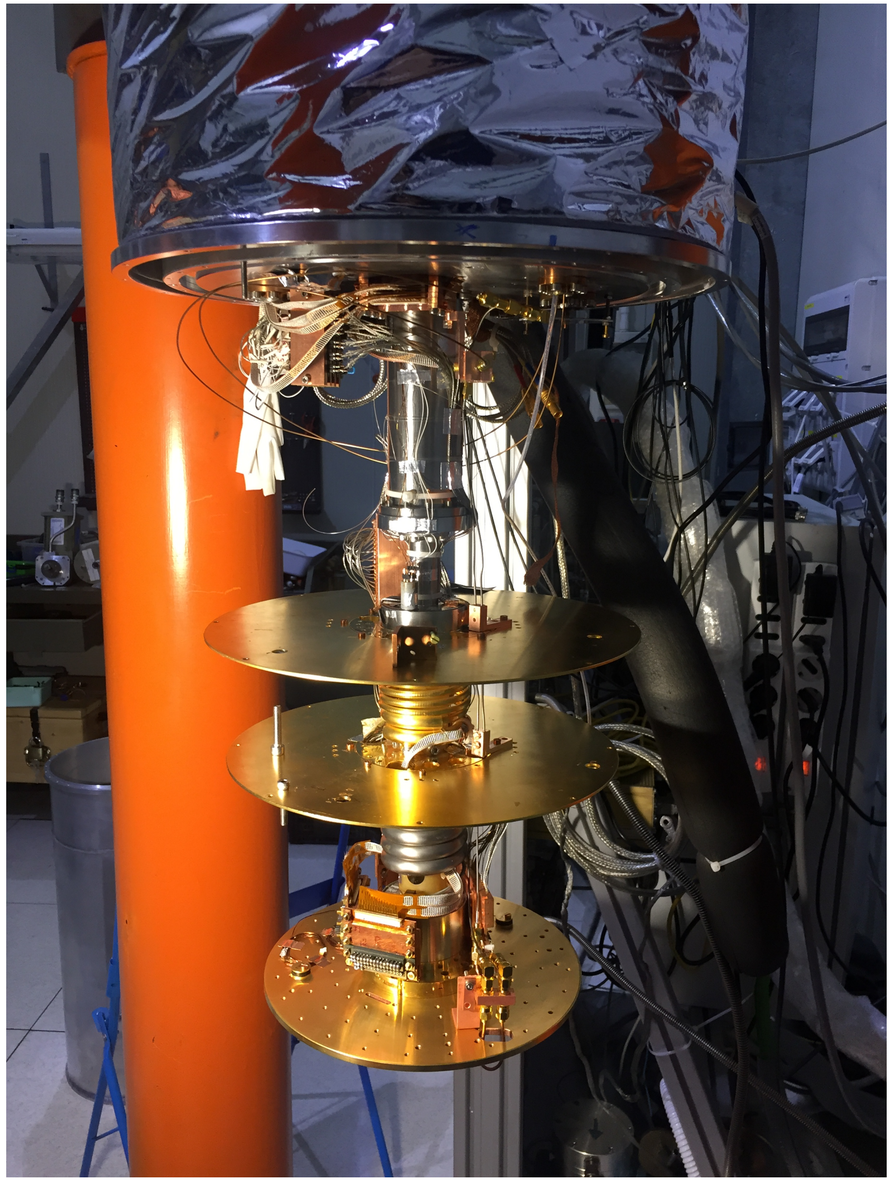
- Long term plan to test final SQMS prototypes
- Middle-term plan: participate to Round Robin





SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Upgrade of LNGS facility (1)

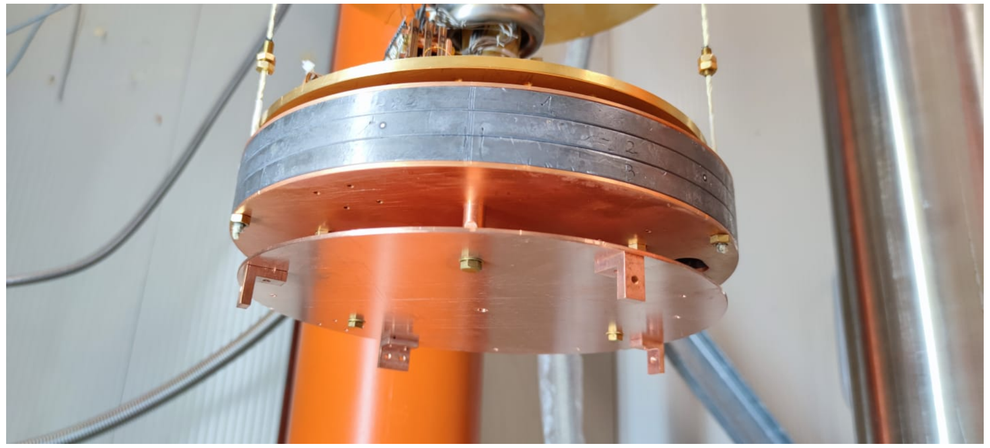


- Underground dilution refrigerator before SQMS
  - Noisy pulse-tube
  - 2 RF lines
  - No RF electronics
  - No room-temperature electronics
  - Short duty cycle (~few days) because of a problem in mixture injection line

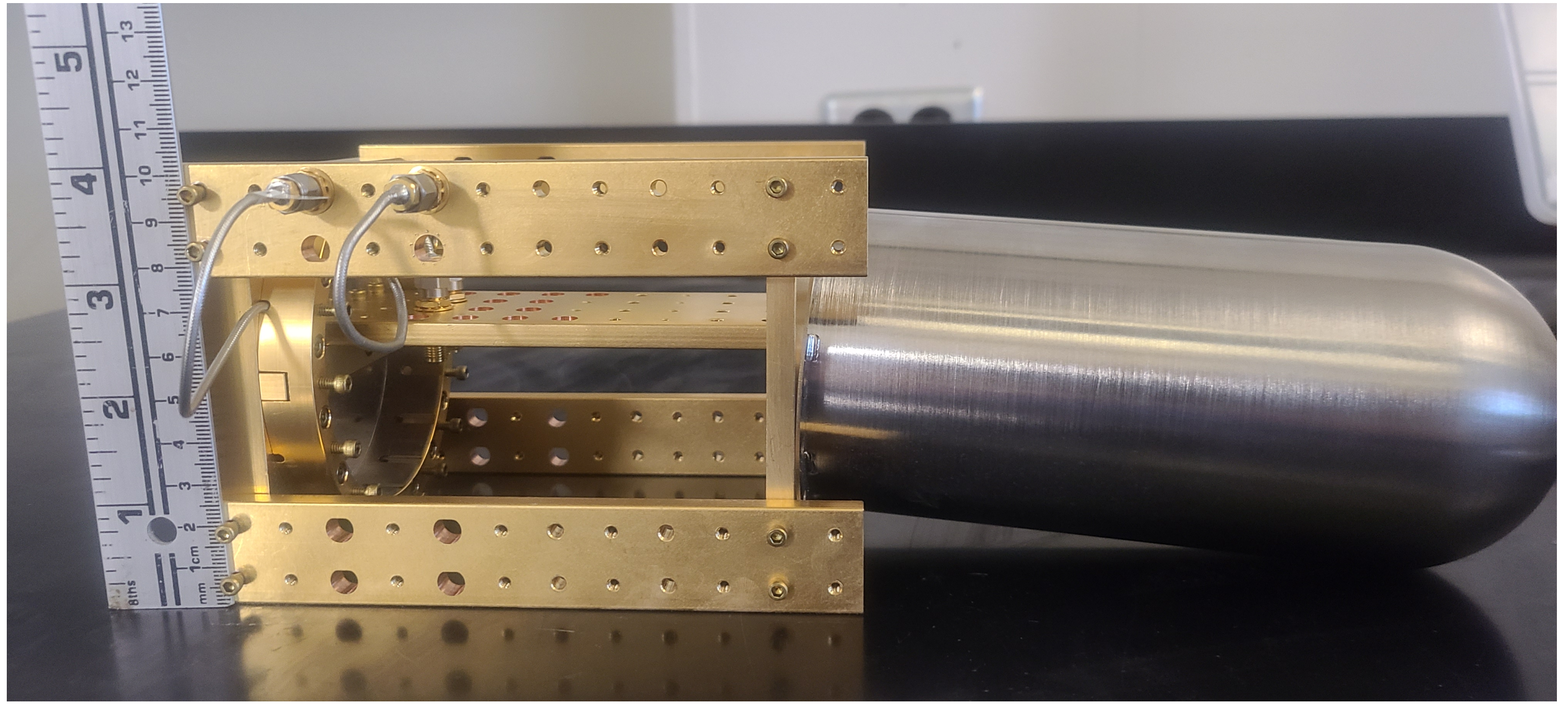
Upgrade of LNGS facility (2)

- During 2020 - 2021:
  - Noisy pulse-tube -> decoupled
  - 2 RF lines -> installed 8 RF lines
  - No RF electronics -> procured amplifier, circulators, insulators, low-pass filters. Placed order for other components (switch and minor stuff)
  - No room-temperature electronics: **to be procured**
  - Short duty cycle (~few days) because of a problem in mixture injection line -> fixed

Upgrade of LNGS facility (3)



- Installed a 2-stage internal lead shield
- Developed and procured the same internal magnetic shield that the other partners will use (now being adapted to our lead shield).



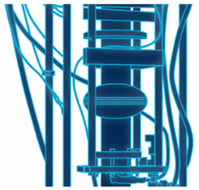
Validation

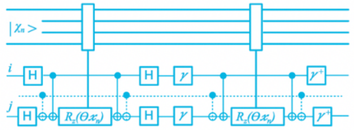
- We borrowed a DEMETRA qubit for a full-test of the system
- Tentative schedule:
  - Installation starting from October 18
  - Cool-down starting from October 25
  - Characterisation by the end of November
  - If successful, we can consider our first deliverable “delivered”
  - (Minor upgrades in progress - switch, amagnetic cables, …)

SQMS Deliverables

Focus Area	Major Activity	Deliverables and Benchmarks	Center Year				
			1	2	3	4	5
Materials for 2D and 3D Quantum Devices	(1) Infrastructure & Testbeds *Impacts: (2), (3), (4), (5),*	Infrastructure upgrades to enable low (T~1.5K) and ultralow (T<=100mK) temperature characterization stations at partner institutions **Risk mitigation: risk reduction via creation of additional testing bandwidth to evaluate new ideas*	■				
		SRF cavity-based testbed available for characterizing dielectrics in quantum regime at Fermilab	■	■	■	■	■
		SRF cavity-based testbed available for characterizing dielectrics in the quantum regime at Northwestern and NIST/UColorado		■	■	■	■
	(2) Advanced Materials Studies *Impacts: (4), (5)* *Drives: (1)*	Initial exploration of dominant quasiparticle sources including underground measurements (INFN) of the 2D Rigetti transmon **Risk mitigation: by testing the same devices in different testbeds by different experimenters, environments and techniques that maximize performance can be identified*	■	■			

- Our obvious contribution: radioactivity
- Generic 2D Rigetti transmon now converged into the Round Robin device

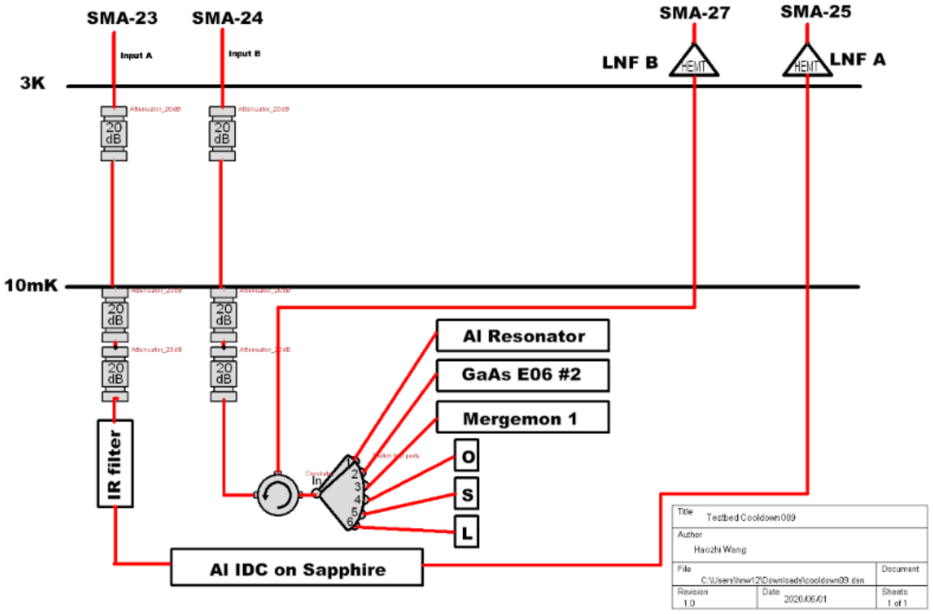


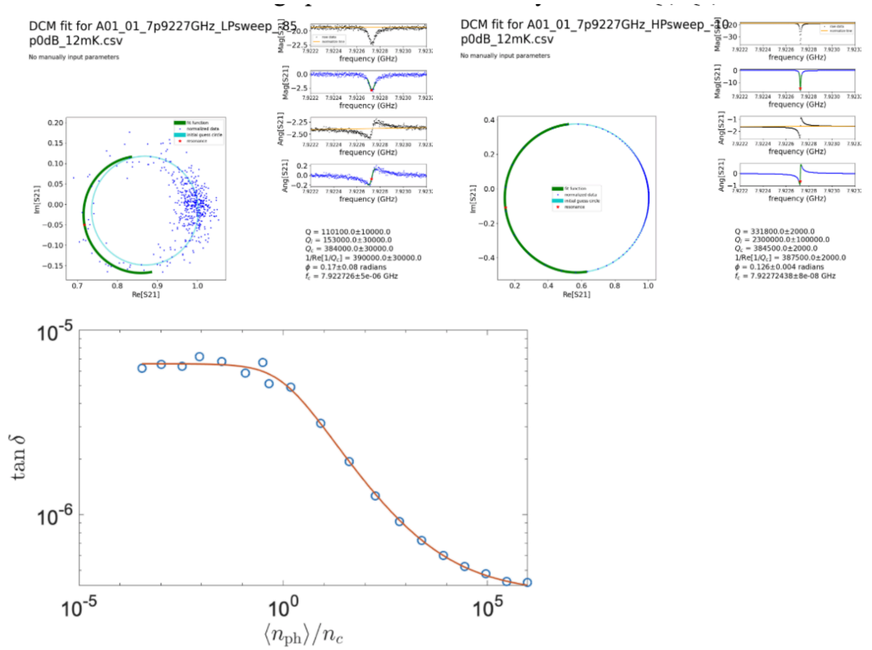


SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Group of Interest: experimental

- Josh Mutus as coordinator
- Boulder University (Corery Rae McRae), FNAL (Roman Pilipenko, Daniil Frolov) and INFN (Laura, Angelo, Ivan and Francesco) + some attendees
- Goal: establish a common protocol for Round Robin measurements





Group of Interest: theorists

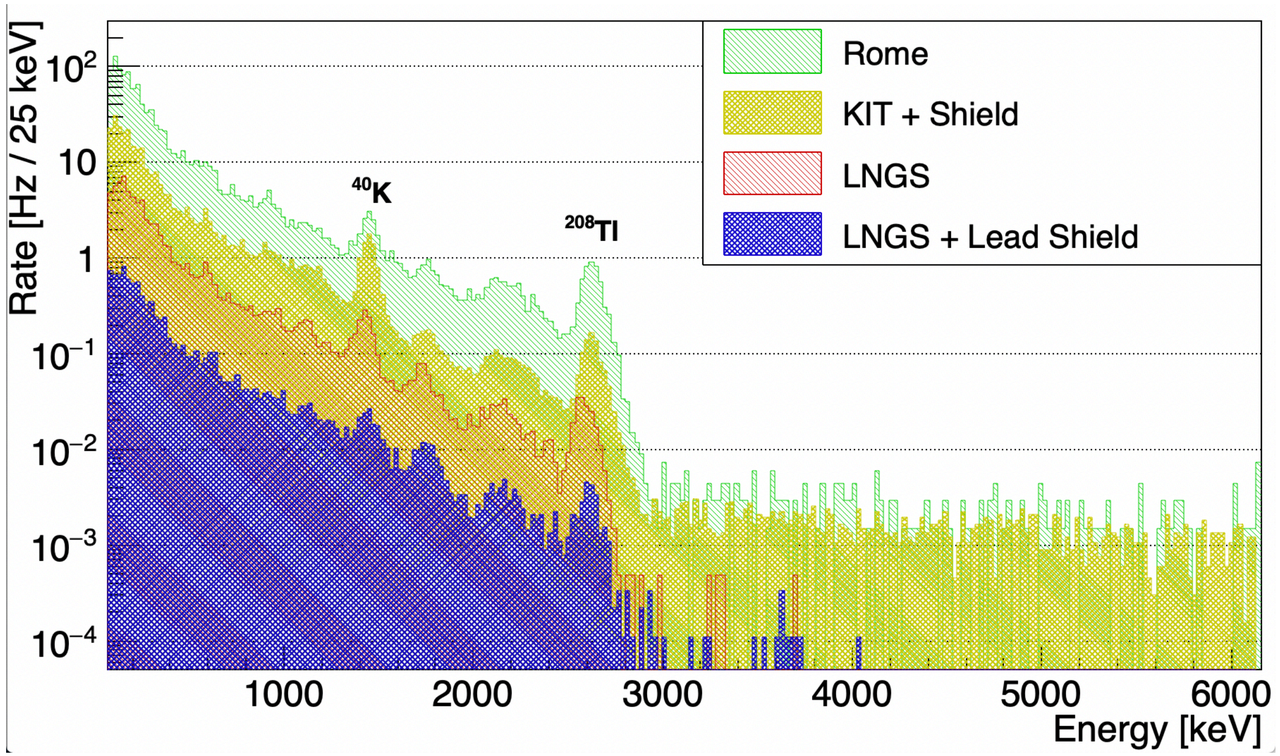
- Many SQMS theorists (Eleanor Rieffel, Jens Koch, Zihui Wang, and many others) to guide us in pushing these measurements beyond the limits
- Try to ask the right questions:
  - Why T1 and T2 vary in time? Why with the thermal cycle?
  - How are they related to the structure/defect of the various components? Can we infer parameters in phenomenological models from our data? Make a list of suspected microscopic models
  - Can we exploit the above to do error mitigation?
  - The noise power spectrum is largely underrated: how can we better measure it, can we use it to design better pulse sequences? Can we change its shape (hole burning, or other techniques?)

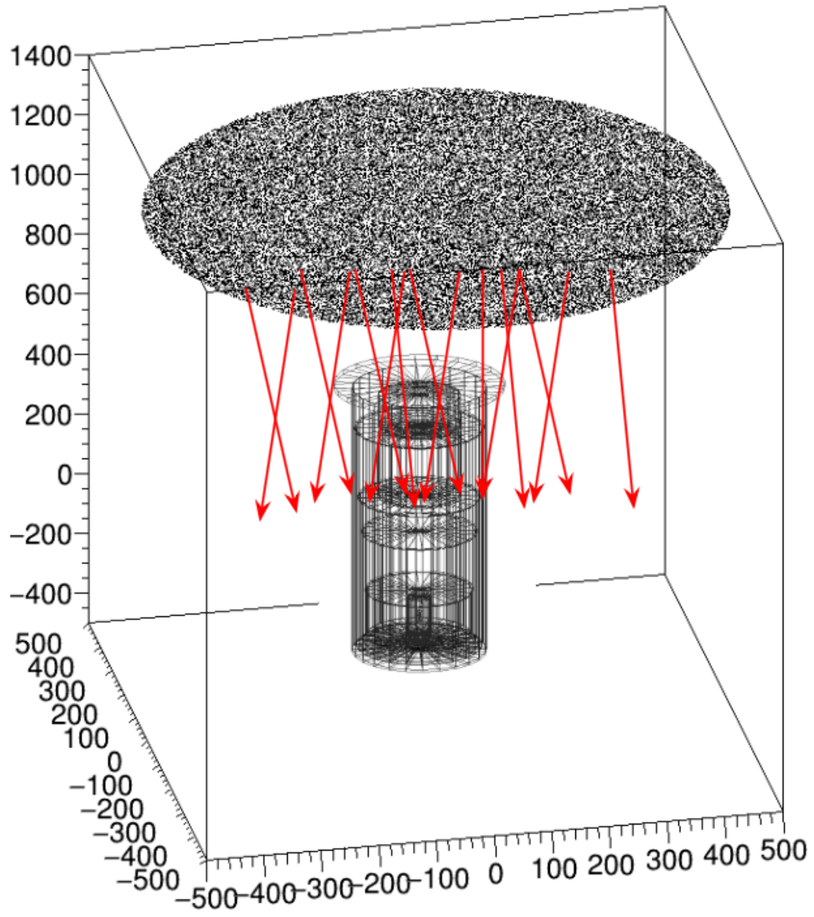
Plan

- By November, validation with DEMETRA qubit
- November: we should receive Keysight electronics, which should arrive in these days at FNAL and be tested there
- Design of PCB for Round Robin in progress (Boulder University)
- Waiting for them to deliver the chip

Decoherence Source: Radioactivity

- Simulations and measurements effort
- (Simplified) geometry of the cryostat and of the sample imported in GEANT-4
- Simulation of external sources (γ, μ, n done, in validation)



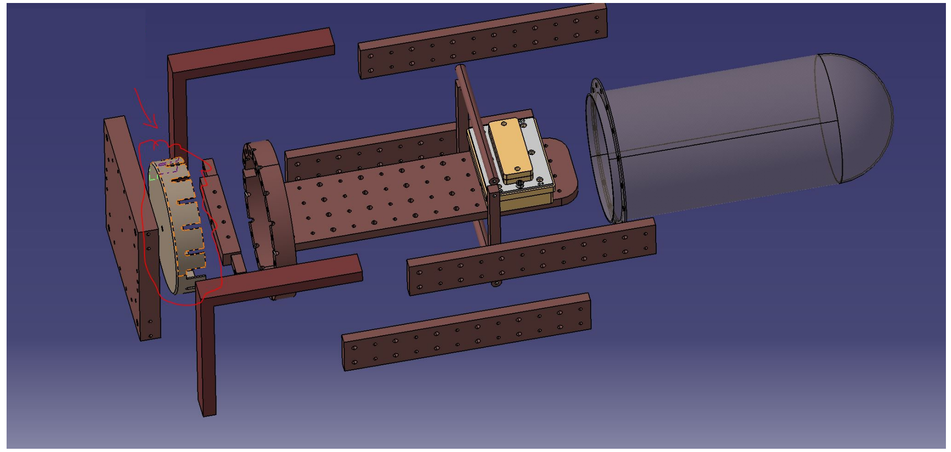


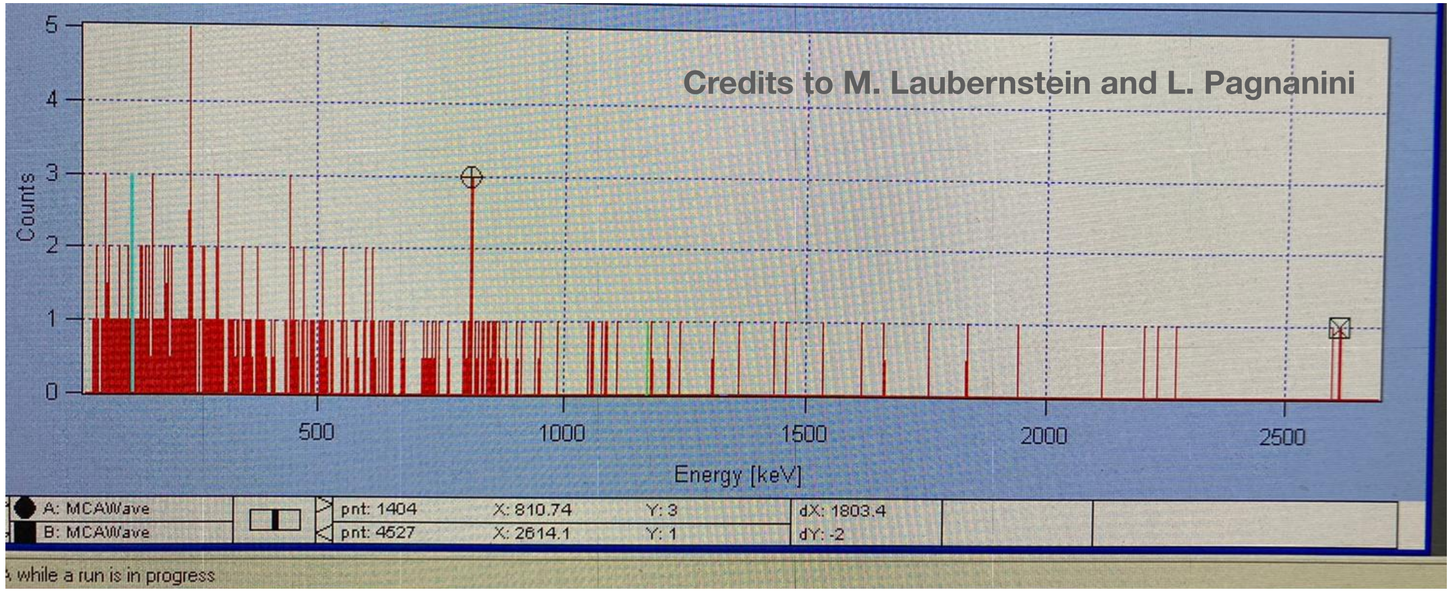
Radioactivity - simulations

- Simulation of external contributions (γ, μ, n done, in validation)
  - Gamma's: about 1 event x minute
    - At LNGS can be decreased by 2 with internal lead shield and by another 7 with external lead shield
  - Neutrons: about 1 event x hour
  - Muons: simulations running
- Are they the dominant radioactive source?

Radioactivity - Materials

- Measurement of the radioactive content of all the involved material
- We proved it is (at least) comparable to external sources
- Of higher interest for international community (protocol)



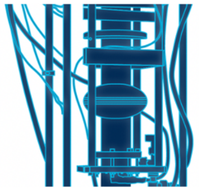


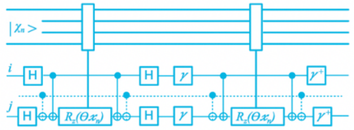
- Typical spectrum (magnetic shield).
- Copper, cold electronics already measured (amplifier, …)
- Now connectors, cables in measurement

SQMS Deliverables

Focus Area	Major Activity	Deliverables and Benchmarks	Center Year				
			1	2	3	4	5
Materials for 2D and 3D Quantum Devices	(1) Infrastructure & Testbeds *Impacts: (2), (3), (4), (5),*	Infrastructure upgrades to enable low (T~1.5K) and ultralow (T<=100mK) temperature characterization stations at partner institutions **Risk mitigation: risk reduction via creation of additional testing bandwidth to evaluate new ideas*	■				
		SRF cavity-based testbed available for characterizing dielectrics in quantum regime at Fermilab	■	■	■	■	■
		SRF cavity-based testbed available for characterizing dielectrics in the quantum regime at Northwestern and NIST/UColorado		■	■	■	■
	(2) Advanced Materials Studies *Impacts: (4), (5)* *Drives: (1)*	Initial exploration of dominant quasiparticle sources including underground measurements (INFN) of the 2D Rigetti transmon **Risk mitigation: by testing the same devices in different testbeds by different experimenters, environments and techniques that maximize performance can be identified*	■	■			

+ SOME SPIN-OFFs



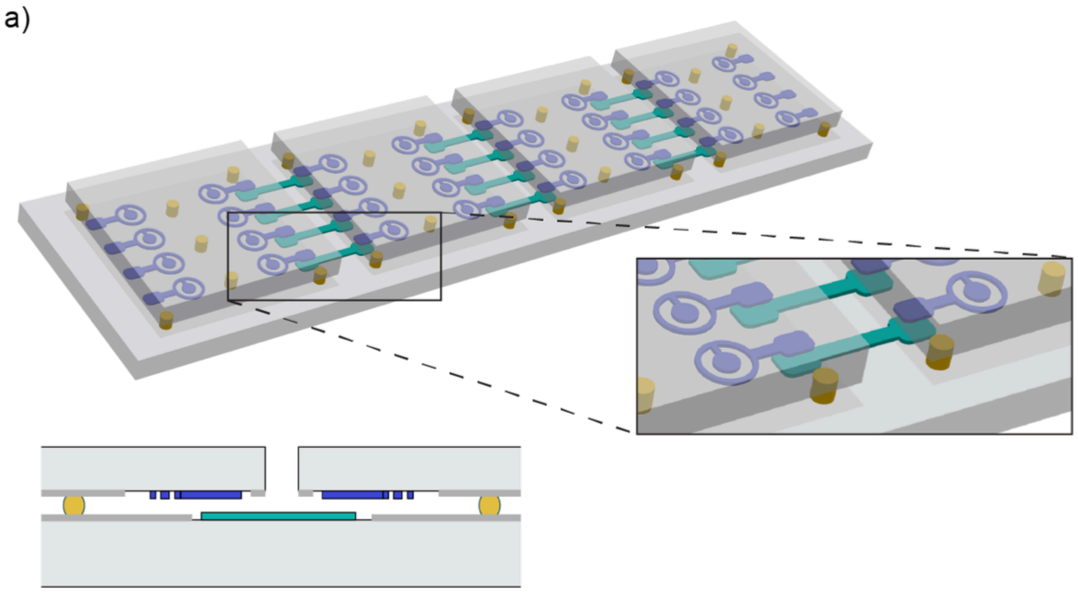


SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

Spin-off

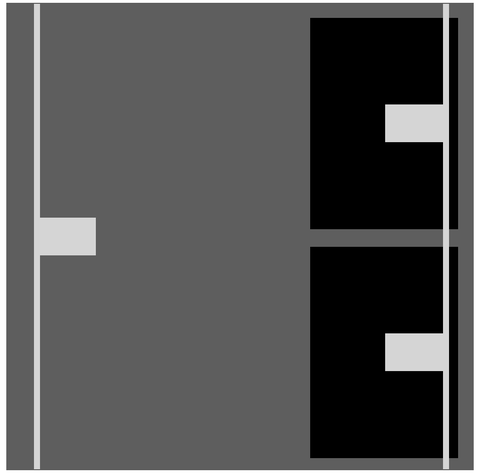
- During an internal meeting with Rigetti, we were asked to perform simulation about radioactivity content also of their **new** devices
- Novel technical solution: block the propagation of phonons from the carrier to the QuICs using an interface made of **indium bumps**
- **We can measure phonon transmission through indium bumps**

Use superconducting resonators (such as those we developed within CALDER, BullKID and related projects) to measure how many phonons go across indium bumps

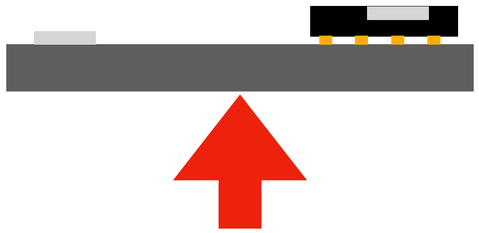


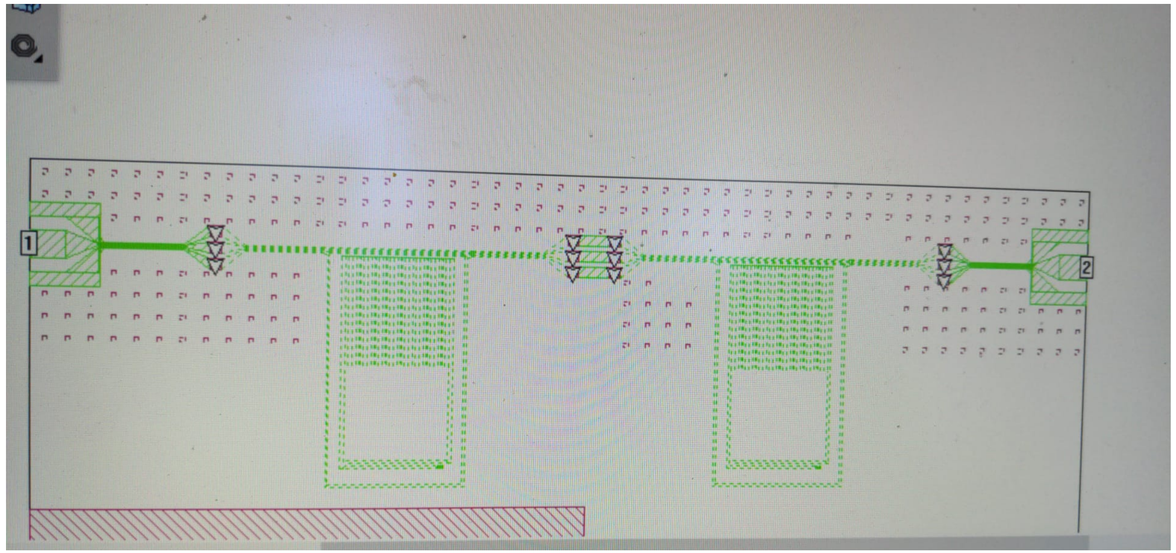
Spin-off 1

Plan for the next weeks



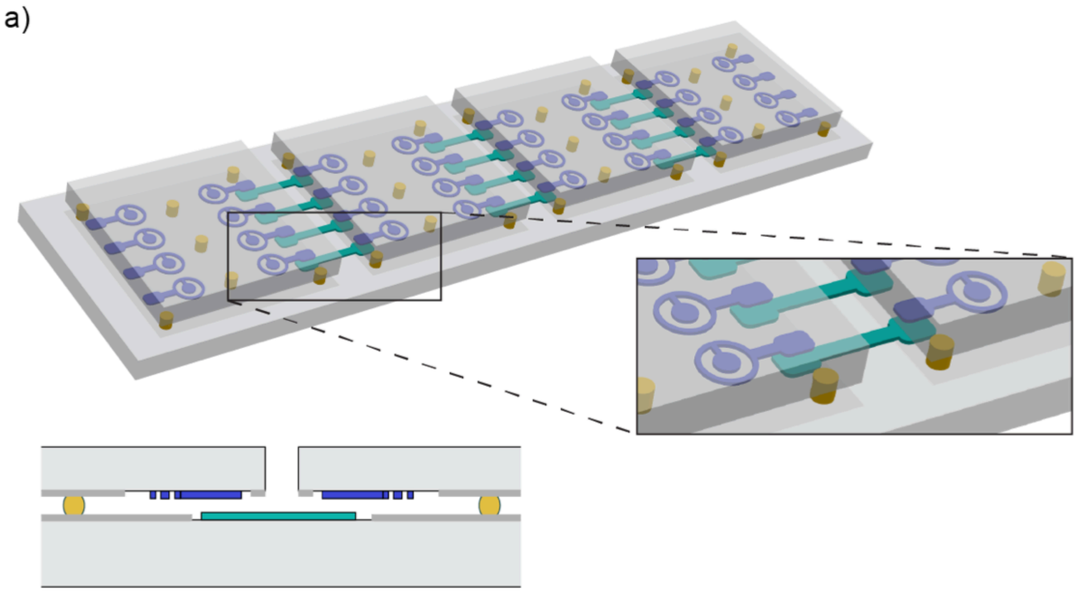
- Finalised the design of this novel detector, procured Si wafers
- Fabrication ~ready to start at CNR
- Rigetti will work on the indium bumps to assemble our detector
- Now iterating with their side





Spin-off 2

- Processor re-designed to be more sensitive to charge (following [Wilen2021], Nature)
- New processor to be tested at Rigetti: quantify correlated errors
- Same processor to be tested at INFN-LNGS
- Assess effect of radioactivity mitigation
- Still in discussion phase - long term



Thanks for the attention

L. Cardani

N. Casali

I. Colantoni (CNR)

A. Cruciani

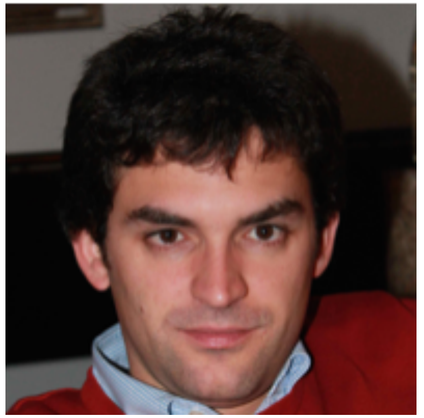
F. De Dominicis (GSSI)

G. D’Imperio

C. Tomei

V. Pettinacci

S. Pirro (LNGS)



M. Vignati (Sapienza)