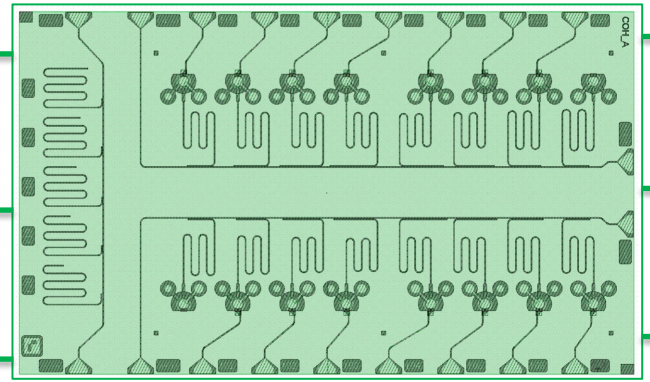
The underground Round Robin

Quantum Technologies for Fundamental Physics, 1–7 Sept 2023 EMFCSC (Erice, Italy)

I Colantoni, L Cardani, N Casali, A Cruciani, F De Dominicis, E Lachman, A Mariani, J Mutus, V Pettinacci, S Pirro, D Van Zanten

The Round Robin

- The device is being transferred between laboratories worldwide to be measured using the same procedures
- Getting a full picture of the decoherence sources
- INFN: focus on “radioactivity” @LNGS



Radioactivity

- External sources

Cosmic muons, neutrons, laboratory radioactivity

Mitigation: passive shielding, location (e.g. underground)

- Internals sources

Materials

Mitigaton: selection of radiopure materials, cleaning

A combination of passive shielding and active background identification (such as muon veto) helps to mitigate the unwanted noise signal

see A. Mariani's poster

Laboratori Nazionali del Gran Sasso (LNGS)

- 1400 m of dolomite rock (3600 m water equivalent)
- Cosmic rays flux attenuation 10^6
- Neutrons (>1MeV) flux attenuation 10^4

Approx:

- μ: ~ 3×10^{-8} / (s · cm^2)
- γ: ~ 1 / (s · cm^2)
- neutrons: ~ 4×10^{-6} / (s · cm^2)

https://arxiv.org/pdf/0912.0452.pdf

The IETI cryostat

40 K

4 K (IVC)

1 st Pb shield

500 mK

50 mK

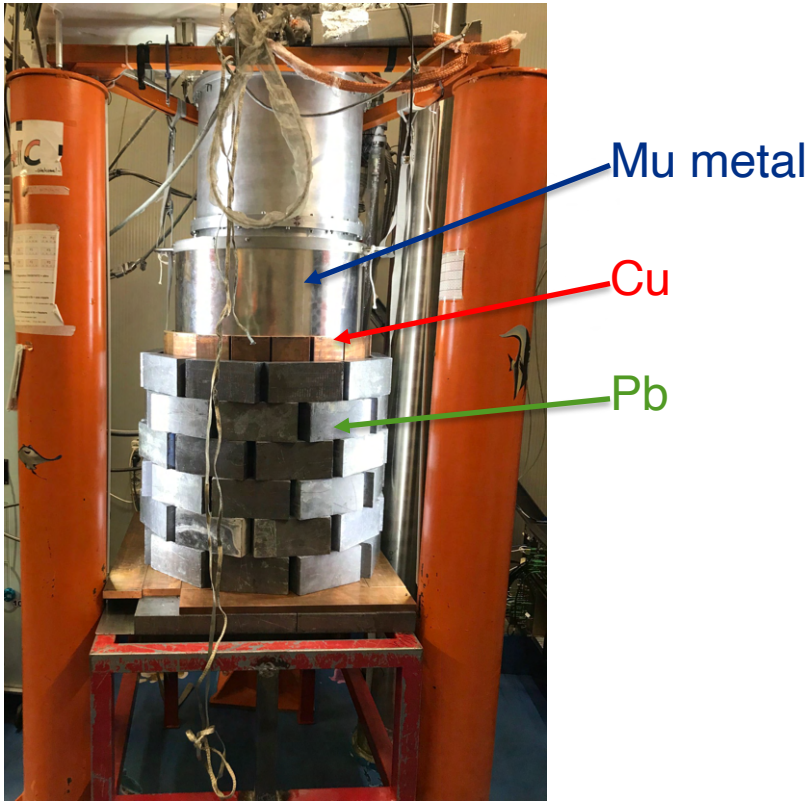
10 mK

2 nd Pb shield

Exp volume

- Dry dilution refrigerator
- Versatile platform that can be used for a variety of experiments with different detectors (KIDs, TESs, bolometers…)
- The experimental volume is decoupled from the pulse tube (dumping the oscillation)
- External and internal shields

IETI passive shields



- Mu metal for magnetic shielding
- Cu for bremsstrahlung shielding
- Pb to suppress the lab radioactivity

A Roman lead shield is ultrapure thanks to 2,000 years under the sea

In this configuration the gamma flux is attenuated by approx one order of magnitude

The radioactivity on our chip in numbers

- 30 mHz above ground (simulated)

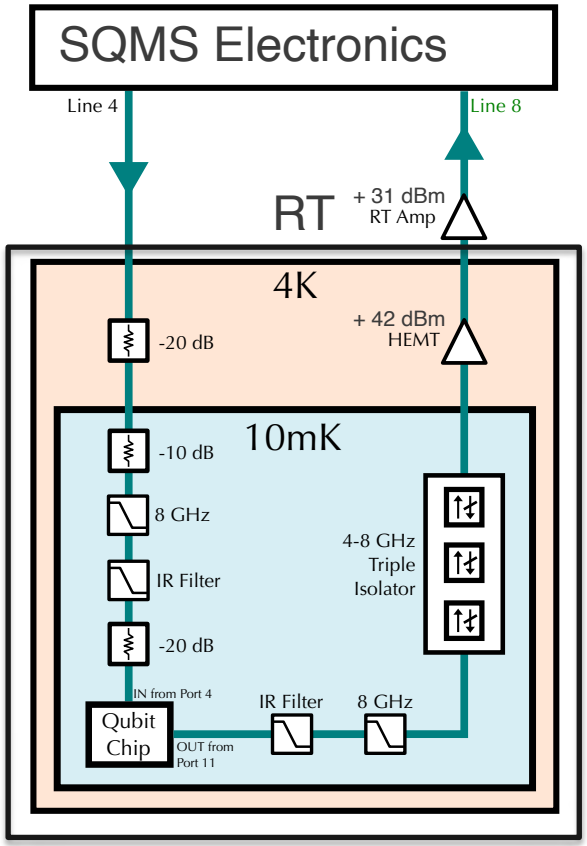
External Sources, underground

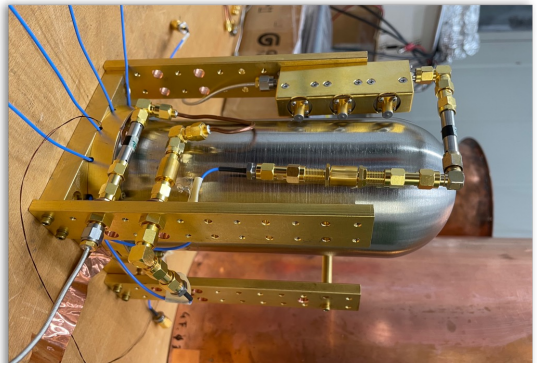
- **1 mHz** on the substrate using 5 cm lead passive shield (simulated+measured)
- **28 mHz** on the substrate using the thorium source (simulated)

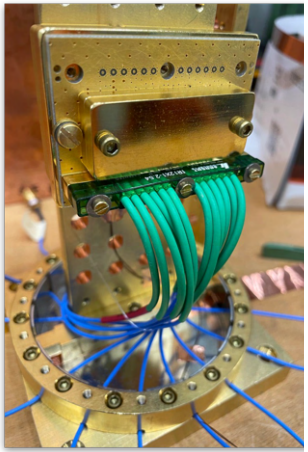
Internal sources

- **5 mHz** from the PCB (measured)

Readout scheme



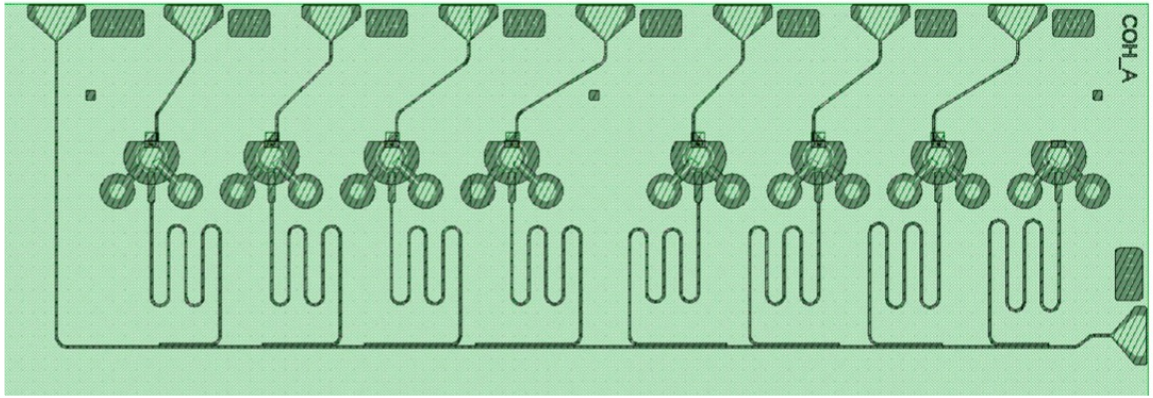




RR package

Fermilab SQMS SUPERCONDUCTING QUANTUM MATERIALS & SYSTEMS CENTER

The run @LNGS

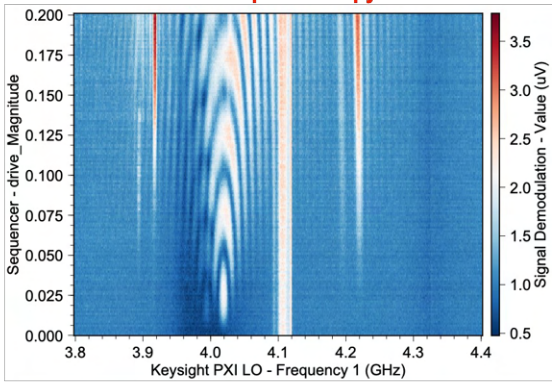


- Measured 2 qubits in 1 week Q8 at fixed frequency, Q13 tunable
- T1, T2, qubit spectroscopy, resonator spectroscopy, rabi oscillation, ramsey
- T1 from Q8 with and without external radioactive source (^{238}Th with measured total activity 300 kBq and 28 mHz on the sample)

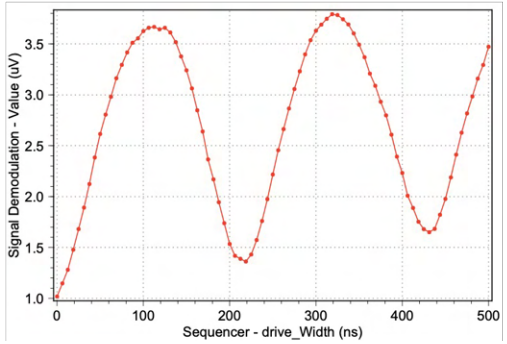
Q8 fine tuning

Preliminary

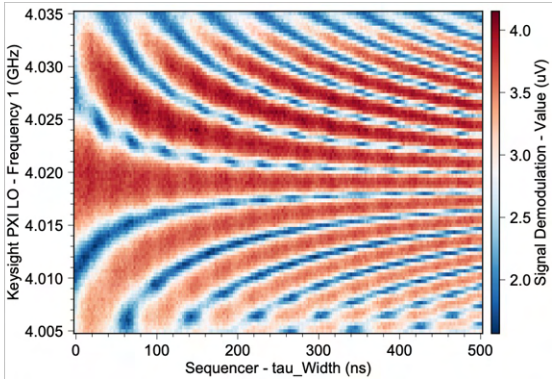
Qubit spectroscopy



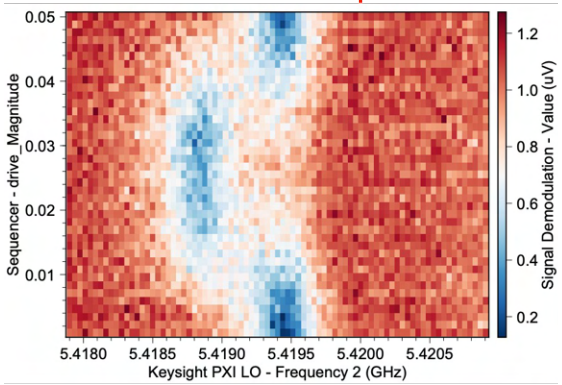
Rabi oscillations



Ramsey



Resonator scan with power



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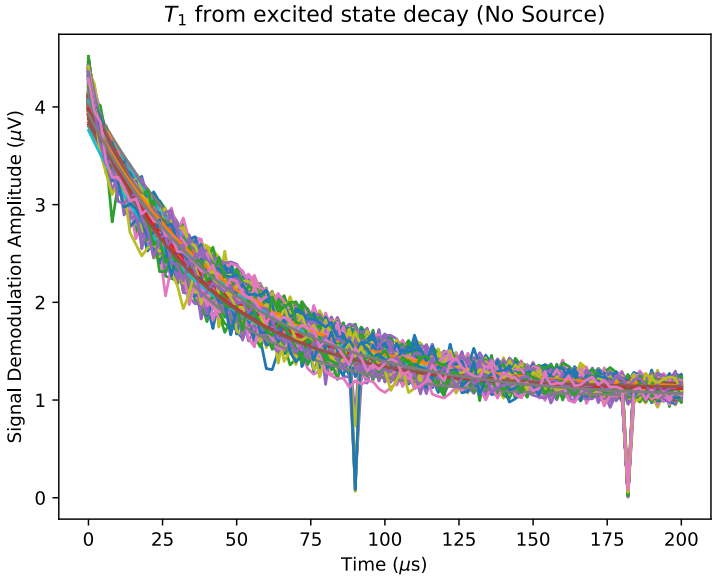
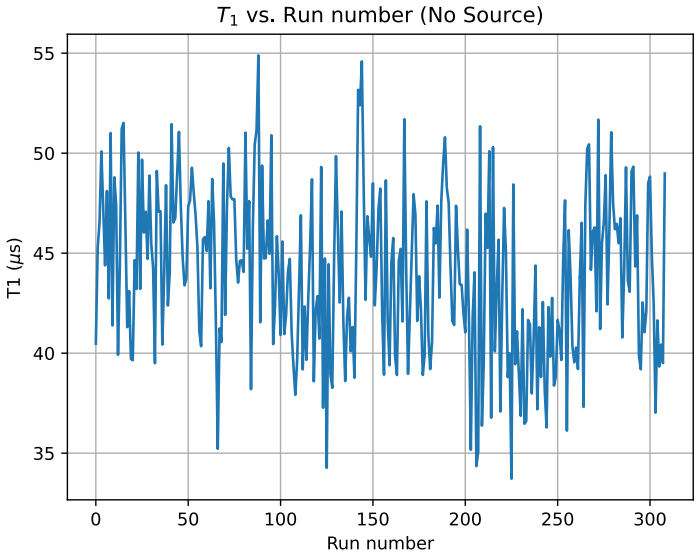
Q8 T1

Preliminary



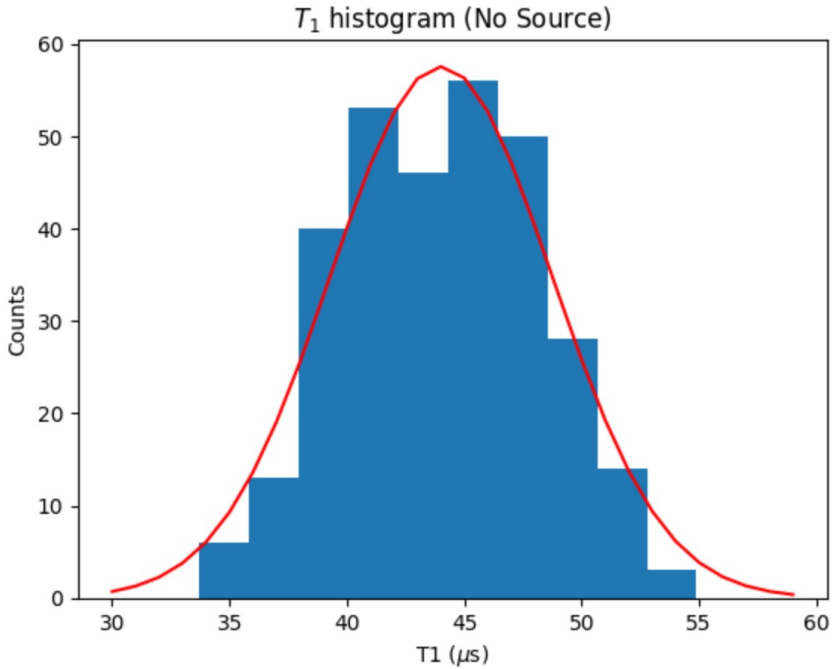


Radioactive source

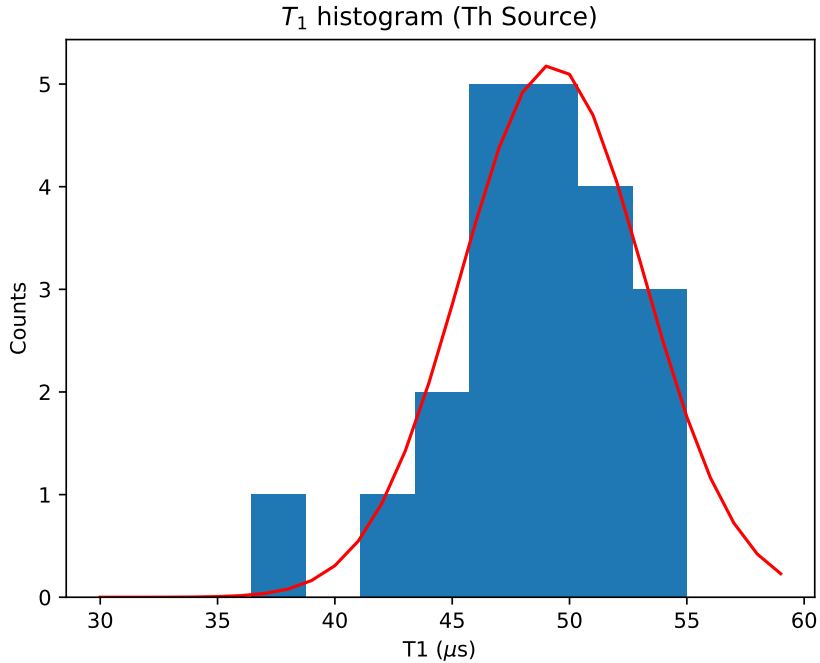
- Thoriated tungsten electrode 300 kBq total activity (measured)
- 28 mHz on the substrate (simulated and measured)
- Inside the lead shield

T_1 histogram Q8

Preliminary



$$T_1 = (44{,}0 \pm 4{,}7)\ \mu s$$



$$T_1 = (48{,}5 \pm 4{,}1)\ \mu s$$

Conclusion

- We developed a fully operational underground facility for superconducting qubit experiments in a low radioactivity environment
- A parametric amplifier is still needed to achieve better fine-tuning of the qubit
- There seems to be no direct effect of the radioactive source on T_1
- Characterizing all qubits will help us to determine the effect of the radioactivity
- New measurements with qubits featuring higher T_1

Thank you for your attention

Contact: ivan.colantoni@cnr.it