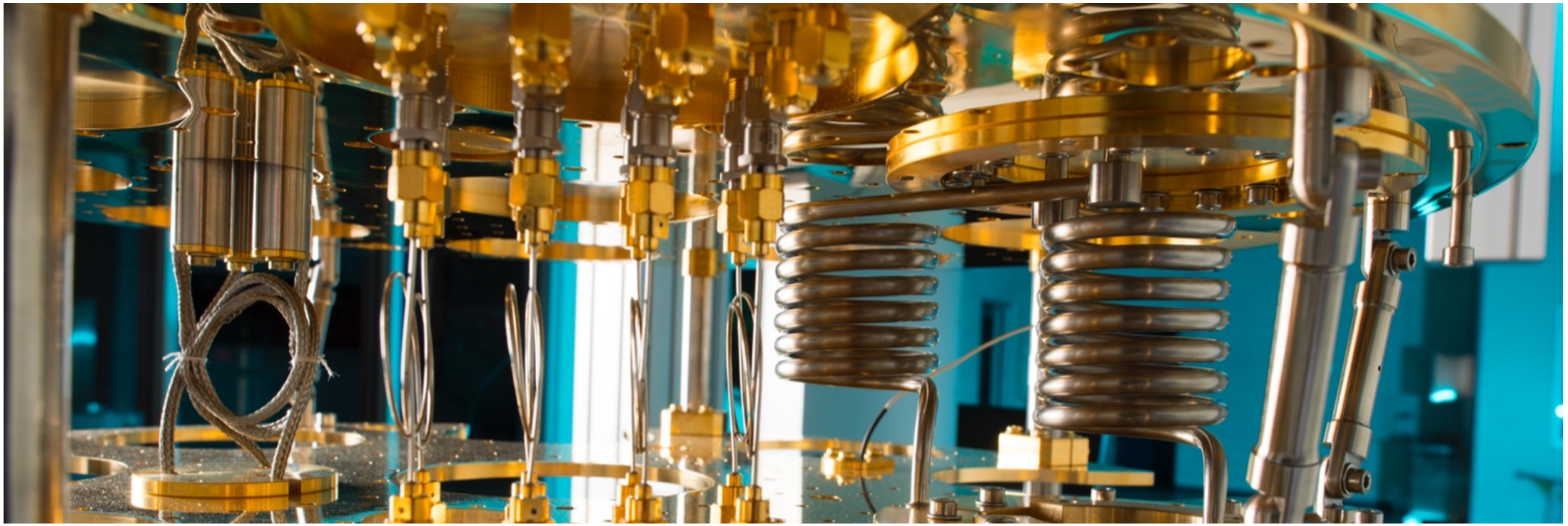
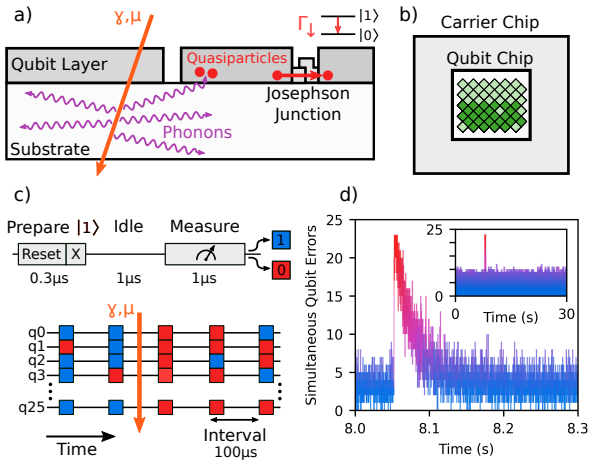


Impact of Radioactivity on Superconducting Qubits

INFN
Istituto Nazionale di Fisica Nucleare

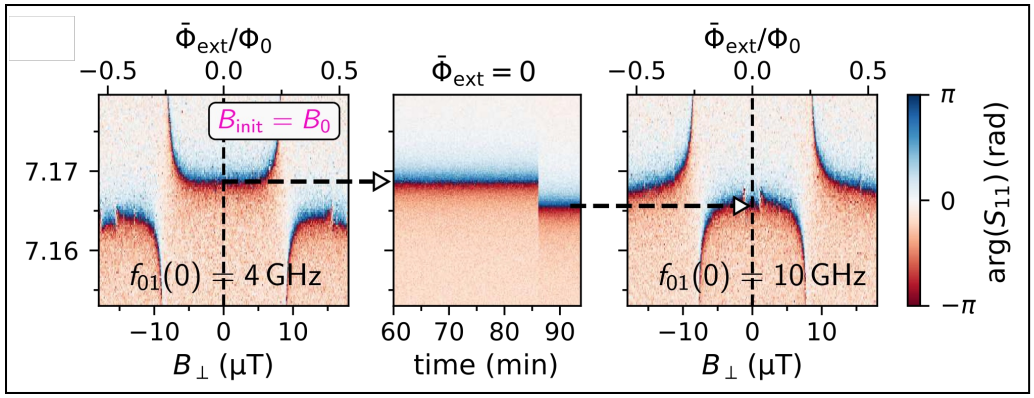
Scientific Background

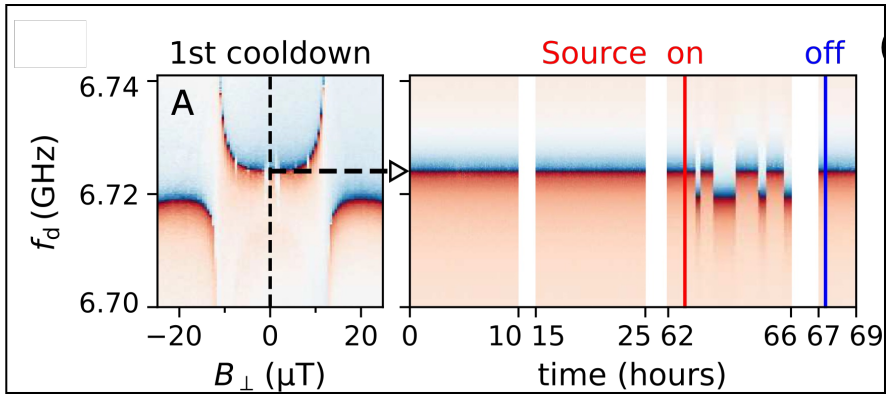
- DEMETRA project (2018): is radioactivity a problem for qubits? Today:
- Radioactivity will limit the coherence of qubits with lifetime at millisecond scale [Vepsäläinen et al, Nature 2020].
  - In standard laboratories, rate of impact: tens of mHz [Cardani et al, EPJ C 2023]
- Radioactivity produces correlated errors
  [Wilen et al, Nature 2021. McEwen et al., Nature Physics 2022.]



Scientific Background

- On the other hand, suppressing radioactivity improves the performance of quantum circuits [Cardani et al, Nature Communications 2021, Gusenkova et al, APL 2022]





This Experiment

- Measure a multi-qubit chip in two scenarios:

Enviroment	Expected muons [mHz]	Expected gamma's (laboratory) [mHz]	Expected Setup – PCB [mHz]
FNAL	8.0	20	<= 5
INFN – LNGS (1.4 km rock overburden) + Lead shield	0	0 Tunable up to 500 with sources	<= 5

This Experiment

- Measure a multi-qubit chip in two scenarios:

Enviroment	Expected muons [mHz]	Expected gamma's (laboratory) [mHz]	Expected Setup – PCB [mHz]	Measured [mHz]
FNAL	8.0	20	<= 5	In progress
INFN – LNGS (1.4 km rock overburden) + Lead shield	0	0 Tunable up to 500 with sources	<= 5	3 Increases with sources

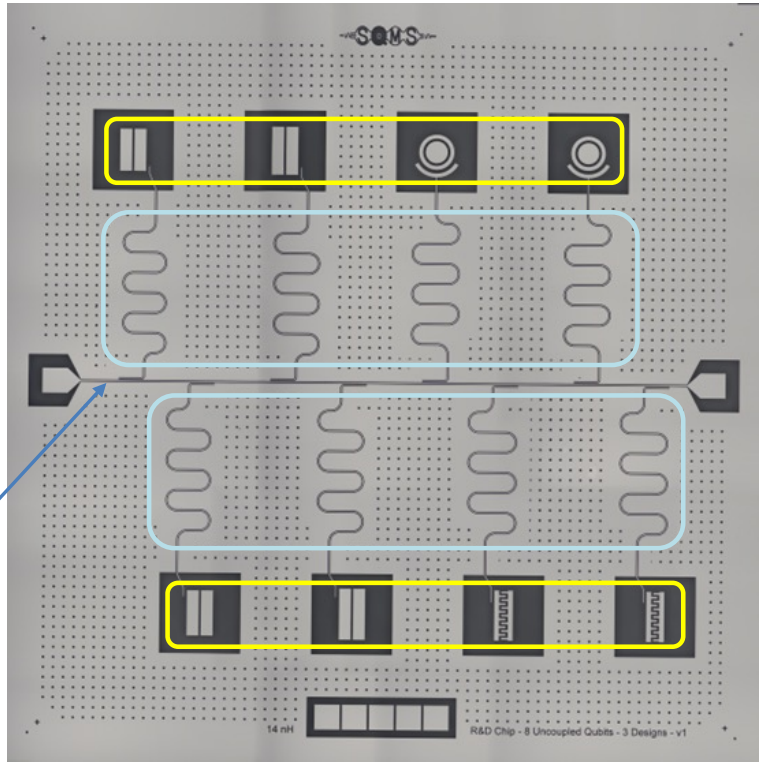
The Sample

- 430 μm, 7.5x7.5 mm Sapphire chip; Nb bottom layer 160 nb, Au top layer 10 nm

Transmons

$\lambda/4$ resonators

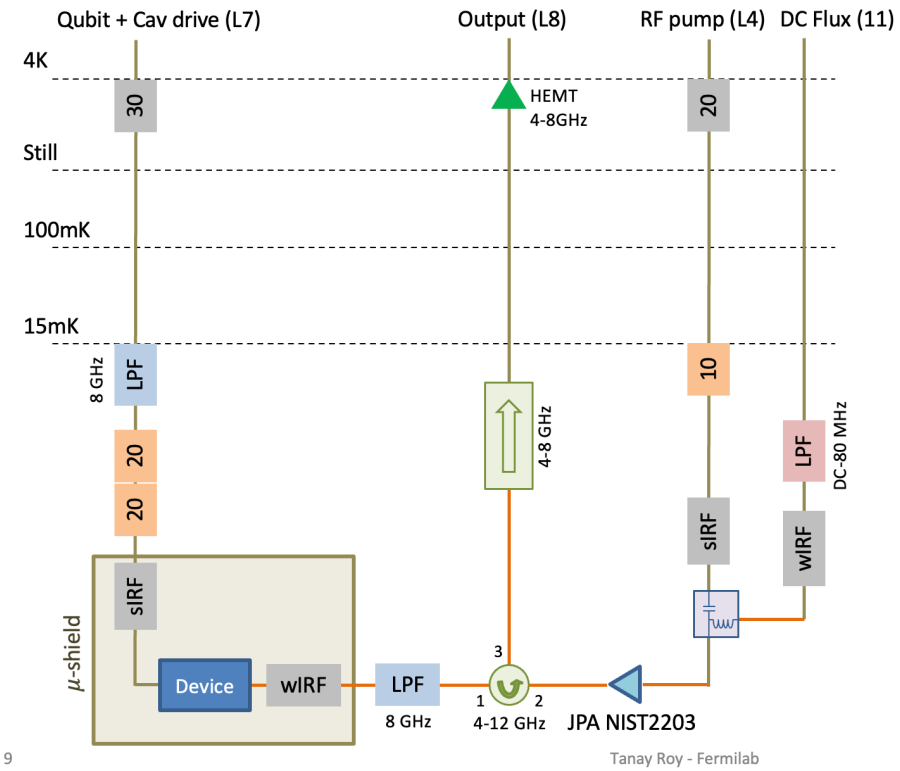
CPW transmission line



Box7-Nb/Au	f_rdt	f_q	T1
1(PP)	7207	4722	115
2(PP)	7037	4655	75
3(PP)	6870	4749	106
4(PP)	6698	4731	90
5(IDC)	6511	4424	65
6(IDC)	6289	4625	75
7(CC)	5899	5131	54
8(CC)	5743	4736	89

- A JPA (4-7 GHz) was added to improve fidelity

Additional Material



LPF MC Low-pass filter

LPF K&L Low-pass filter

HPF High-pass filter

IRF QM - Infrared filter

10 XMA SS-body att

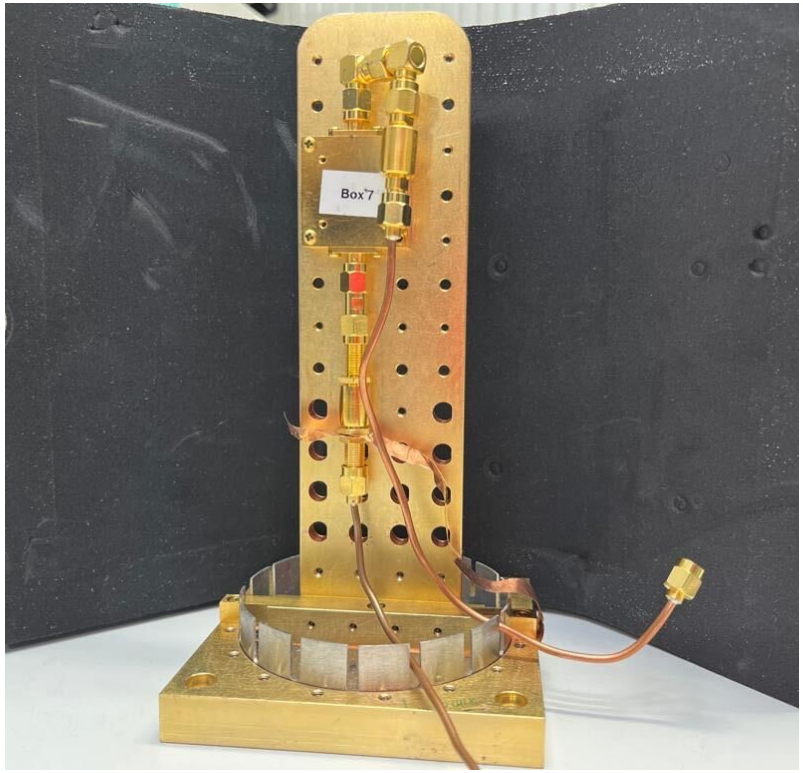
20 XMA Cu-body att

(Triple J) LNF Isolator

LNF Circulator

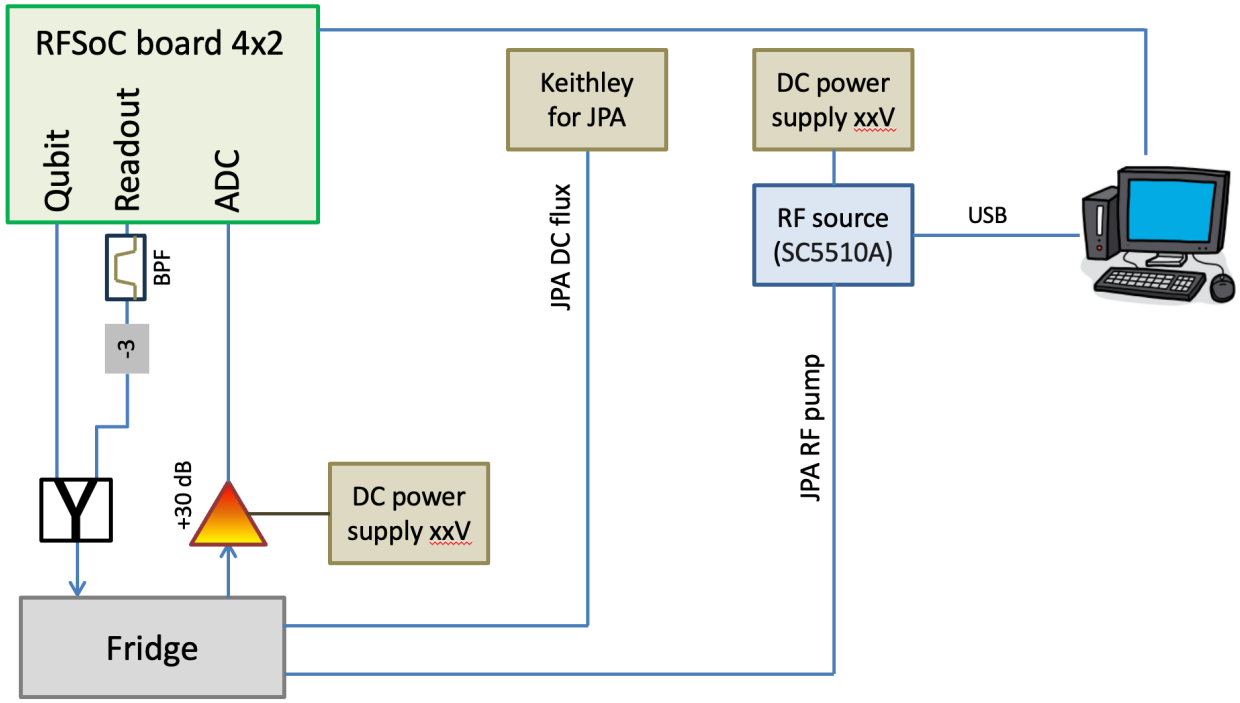
Diplexer

Mounting at INFN - LNGS



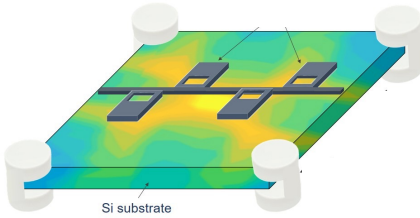
Readout

- QICK (RFSoC 4x2) – credits to G. Cancelo (FNAL)



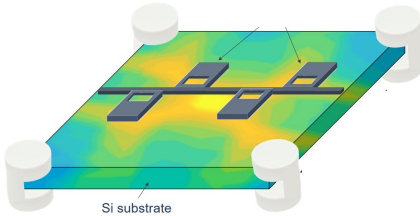
Measurement Strategy

- Effect of radioactive interaction: produce phonons in substrate that can stay there for as long as milliseconds
- All qubits in 1 would decay into 0 (again and again) until phonons are evacuated:
  - Prepare qubit in 1
  - Measure its status after 10 μs
  - If no phonons are there, it is very likely that we will find it in 1
  - If phonons are there, it is very likely that we will find it in 0
  - Repeat



Measurement Strategy

- Effect of radioactive interaction: produce phonons in substrate that can stay there for as long as milliseconds
- All qubits in 1 would decay into 0 (again and again) until phonons are evacuated:
  - Prepare qubit in 1
  - Measure its status after 10 μs
  - If no phonons are there, it is very likely that we will find it in 1
  - If phonons are there, it is very likely that we will find it in 0
  - Repeat



- In absence of radioactive events: 1 – 1 – 1 – 1 – 1 – 1 – 1 – 1 – 0 – 1 – 1 ….
- In presence of radioactive events: 1 – 1 – 1 – 0 – 0 – 0 – 0 – 0 – 1 – 1 ….
  - The number of 0's will depend on how long phonons are there
  - Fast sampling needed

Conclusion

- The HW/SW work – minor optimizations still possible
- Preliminary results show that
  - Qubits operated in muon-free environment see anyway events produced by gamma radioactivity
  - The effect on our sample is on the millisecond scale

Thanks for the Attention

- In the picture:
  - L. Cardani, F. De Dominicis, M. Iannone, A. Mariani, T. Roy (that we also thank for many figures shown in these slides) and D. Helis
- Not in the picture:
  - M. Bal, F. Crisa, A .Grassellino, R. Pilipenko, A. Romanenko, D. van Zanten (FNAL)
  - A. Cruciani, I. Colantoni, V. Pettinacci, S. Pirro, M. Vignati (INFN)
  - E. Lachman, J. Mutus (Rigetti)