

Characterizing qubit decoherence deep underground at SNOLAB

Tyler Reynolds

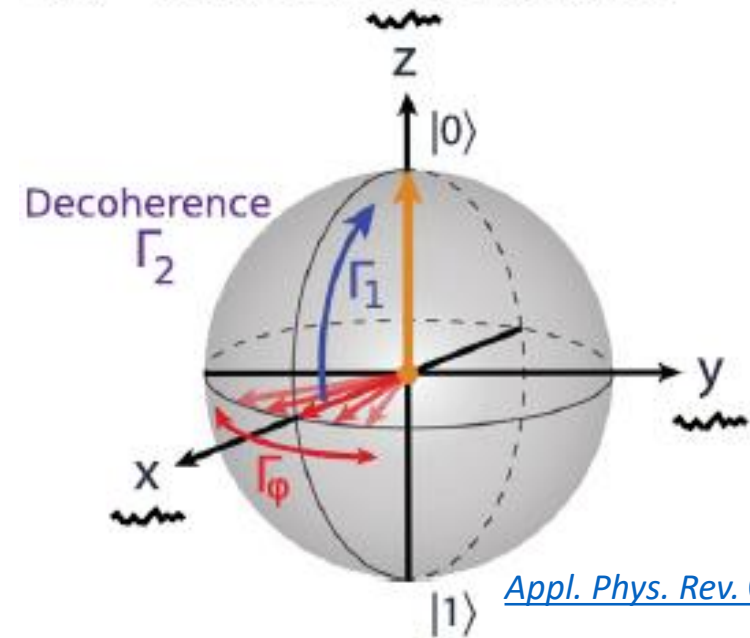
On behalf of the QUTEbits Collaboration

June 12, 2025

Qubits and Coherence

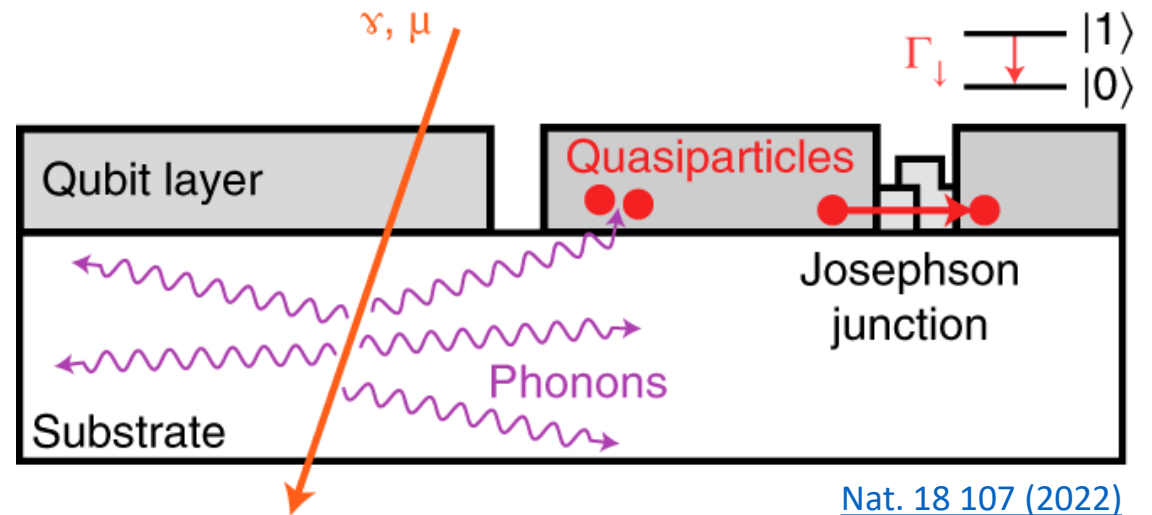
- Superconducting qubits exploit quantum superpositions to carry out complex quantum algorithms
- Superposition states decohere in time
 - T_1 – relaxation
 - T_2 – decoherence
- Interactions with the environment \rightarrow decoherence \rightarrow errors

(d) Transverse relaxation



Coherence Times and Cosmic Rays

- Coherence times still limited by several sources
- Correlated errors = no error correction
- Larger than expected populations of non-equilibrium quasiparticles observed ([Serniak 2018](#))
- Ionizing radiation can contribute to this population
 - Material contamination
 - **Cosmic rays**



The QUTEbits Collaboration

- QUTEbits Collaboration
 - SNOLAB
 - Chalmers University of Technology
 - Institute for Quantum Computing at University of Waterloo
- Goals
 - Study impact of cosmic rays on qubit decoherence
 - Explore qubit performance in different radiation environments
 - Kickstart quantum computing program at SNOLAB

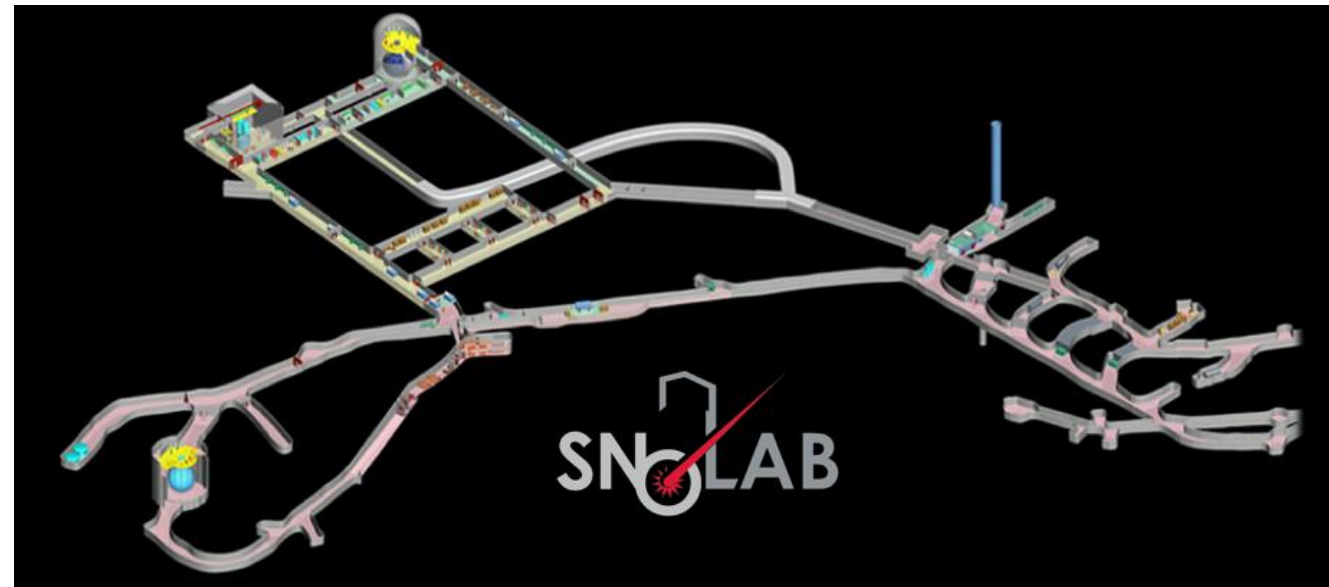


CHALMERS
UNIVERSITY OF TECHNOLOGY

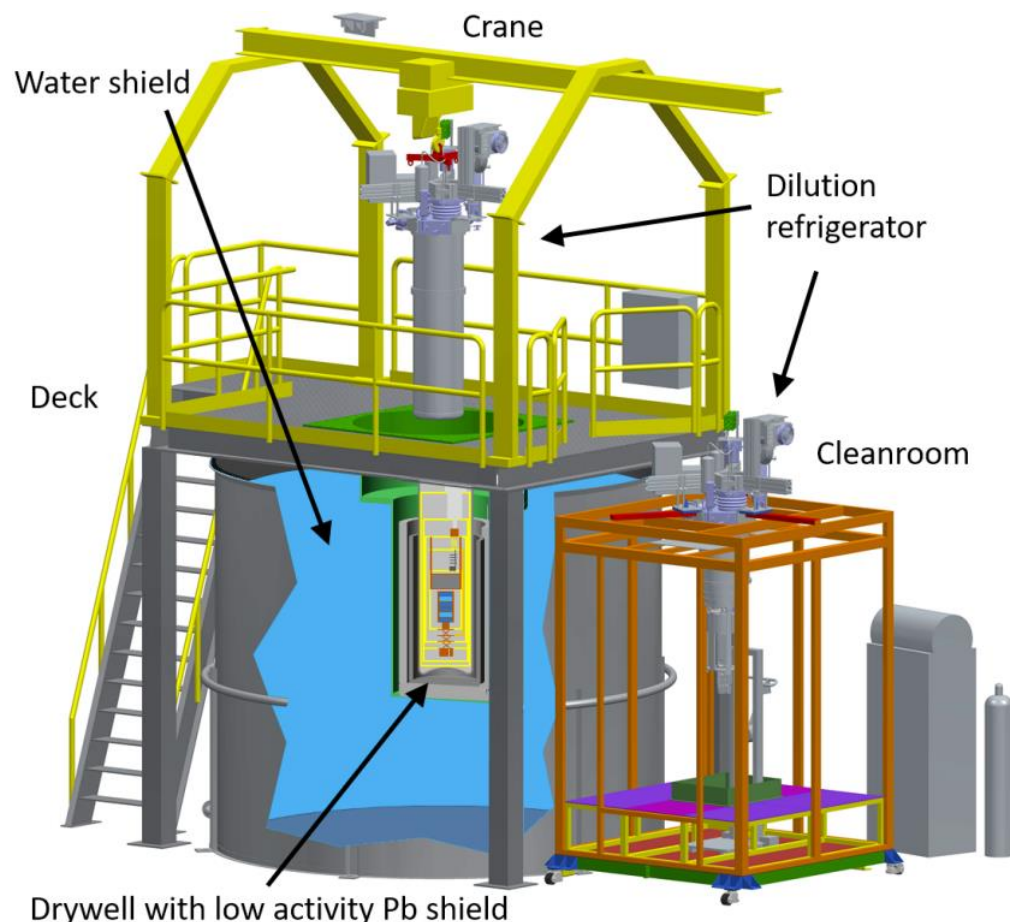


SNOLAB

- Located in Sudbury, ON
- 2 km rock overburden shields from cosmic rays (6 km.w.e.)
 - Muon flux of $0.27/\text{m}^2/\text{day}$
- Class 2000 cleanroom



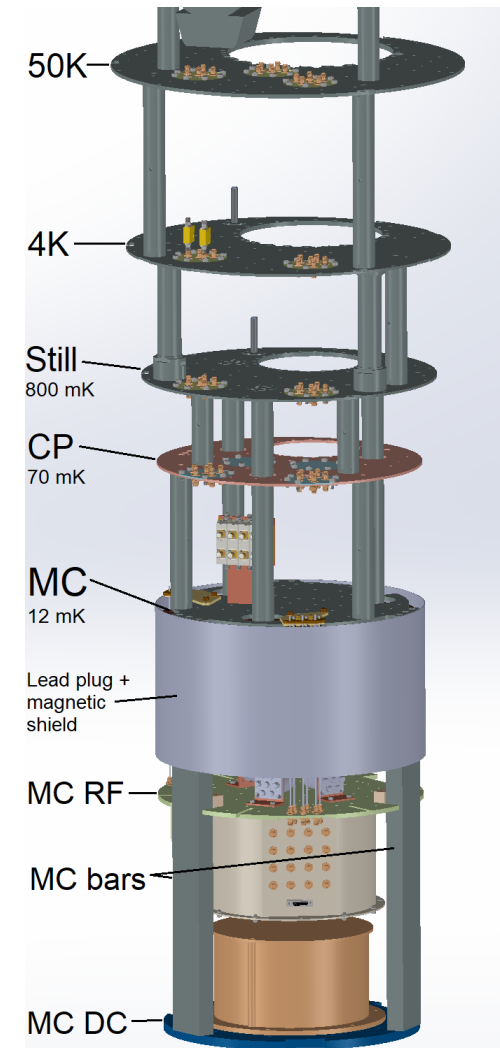
CUTE Facility



- **Cryogenic Underground Test Facility**
- Dilution refrigerator
 - Base temperature: 12 mK
- Class-300 clean room
- Low background test facility
- Access to two calibration sources
 - ^{252}Cf (37.5 kBq) for neutrons
 - ^{133}Ba (37 kBq) for gammas
- For more info see [Front. Phys. 10](#)

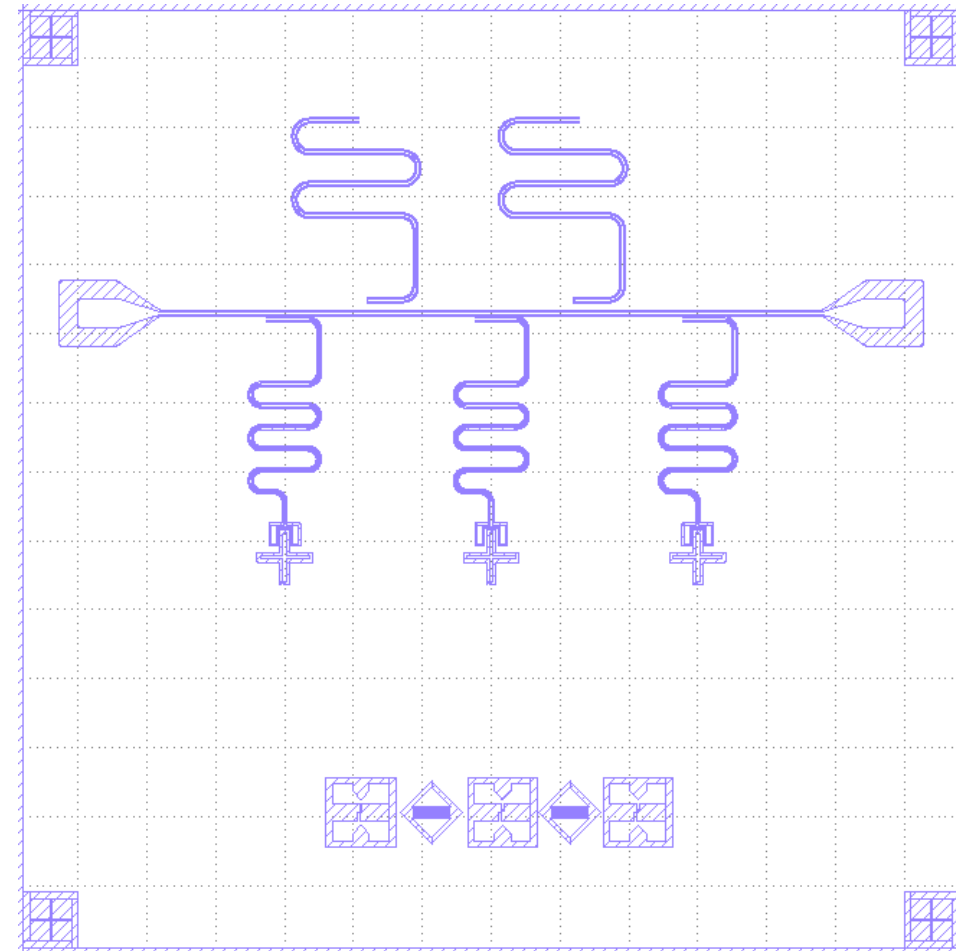
CUTE Facility Upgrades

- Facility originally supported “DC” payloads (such as transition edge sensor calorimeters)
- New facility supports up to 12 RF lines with rigid coax cables
- New sample plate and magnetic shield for qubit devices
- Can simultaneously run RF and DC payloads



Initial Payload

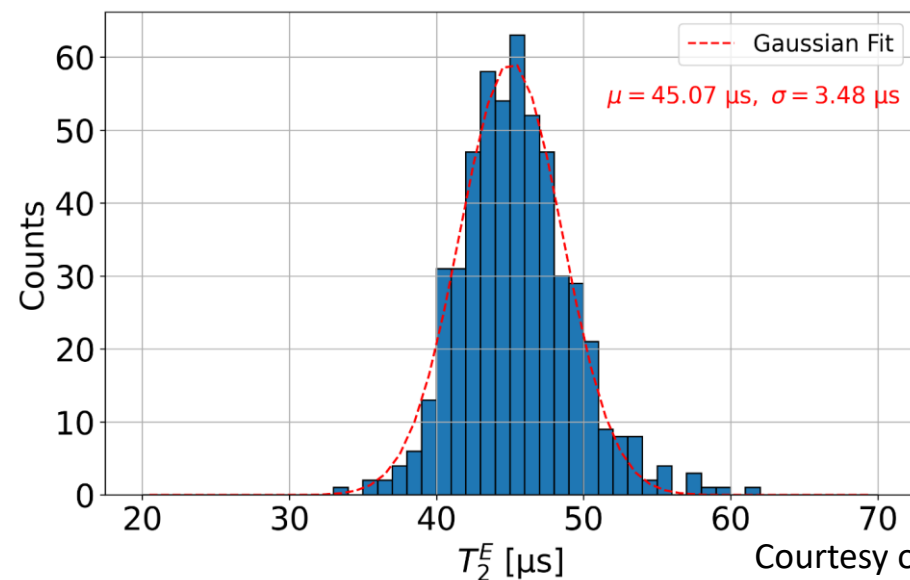
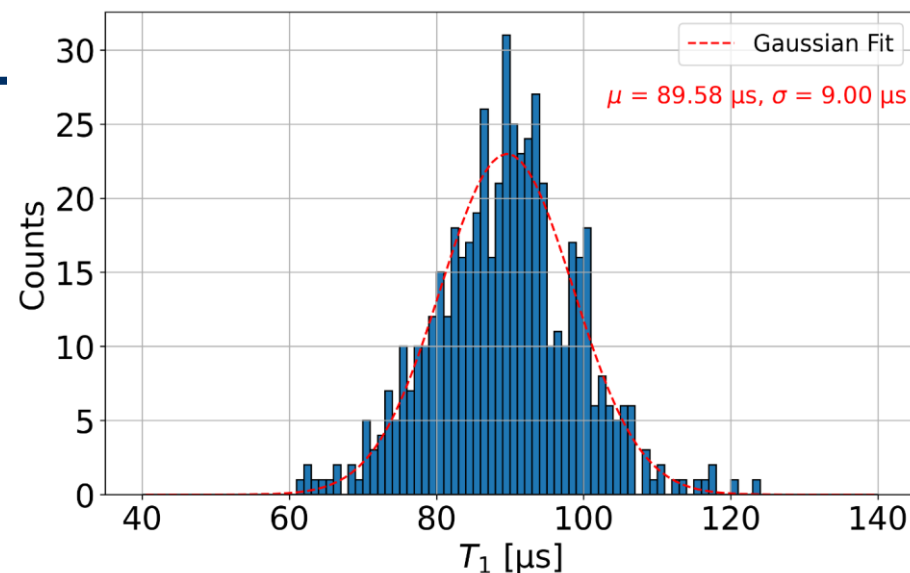
- **Single transmon chip**
 - 3 qubits with corresponding readout resonators
 - 2 high- Q_C resonators
- Measured at surface facility in Waterloo
 - $E_J/E_C = 28.29$
 - $f_{01} = 3.371$ GHz
 - $T_1 = 90$ μ s
 - $T_2^{\text{Echo}} = 45$ μ s
 - Effective temperature = 62.21 mK



Courtesy of G. Peng

Initial Payload

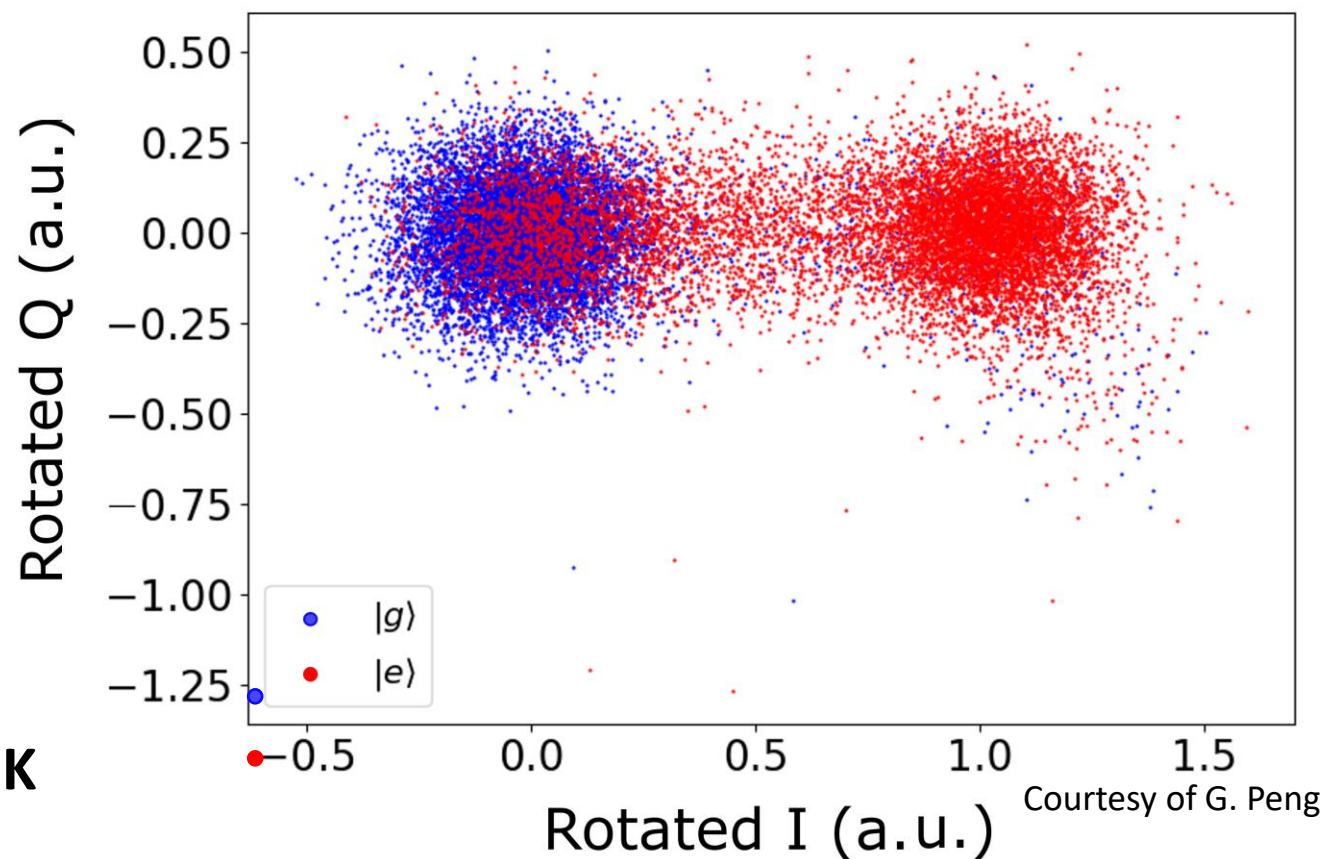
- Single transmon chip
 - 3 qubits with corresponding readout resonators
 - 2 high- Q_C resonators
- Measured at surface facility in Waterloo
 - $E_J/E_C = 28.29$
 - $f_{01} = 3.371$ GHz
 - $T_1 = 90 \mu\text{s}$
 - $T_2^{\text{Echo}} = 45 \mu\text{s}$
 - Effective temperature = 62.21 mK



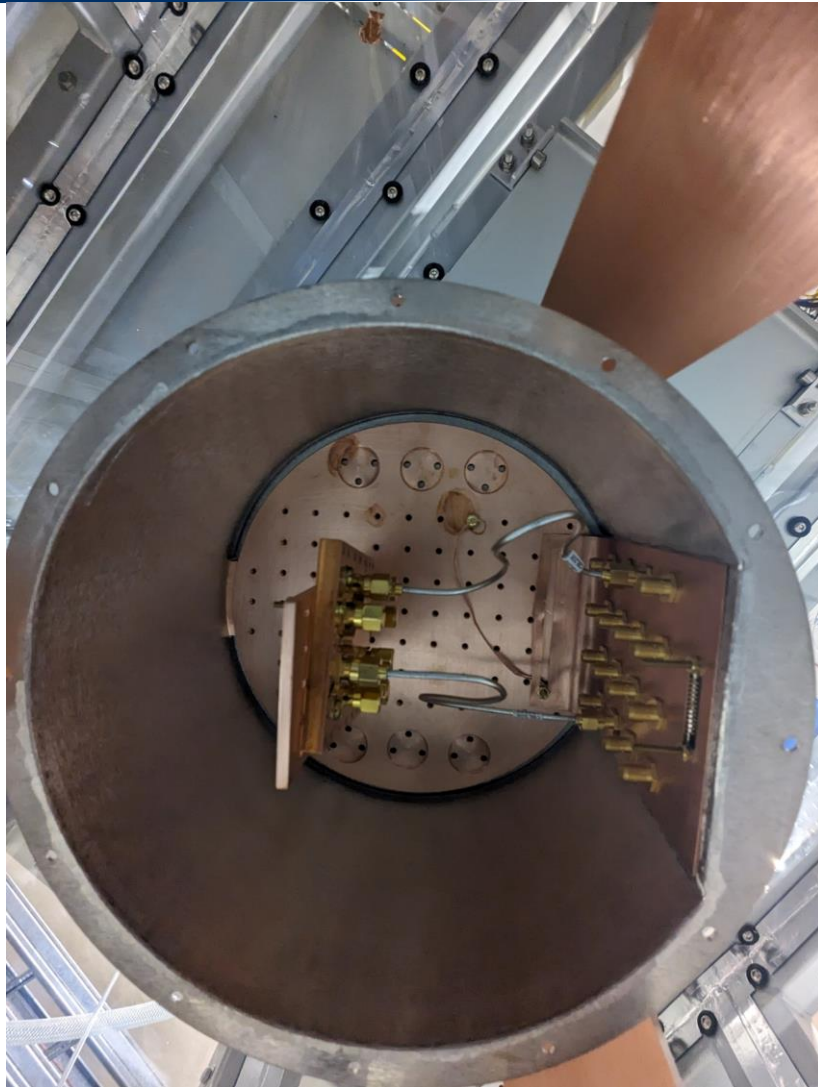
Courtesy of G. Peng

Initial Payload

- Single transmon chip
 - 3 qubits with corresponding readout resonators
 - 2 high- Q_C resonators
- Measured at surface facility in Waterloo
 - $E_J/E_C = 28.29$
 - $f_{01} = 3.371$ GHz
 - $T_1 = 90$ μ s
 - $T_2^{\text{Echo}} = 45$ μ s
 - **Effective temperature = 62.21 mK**

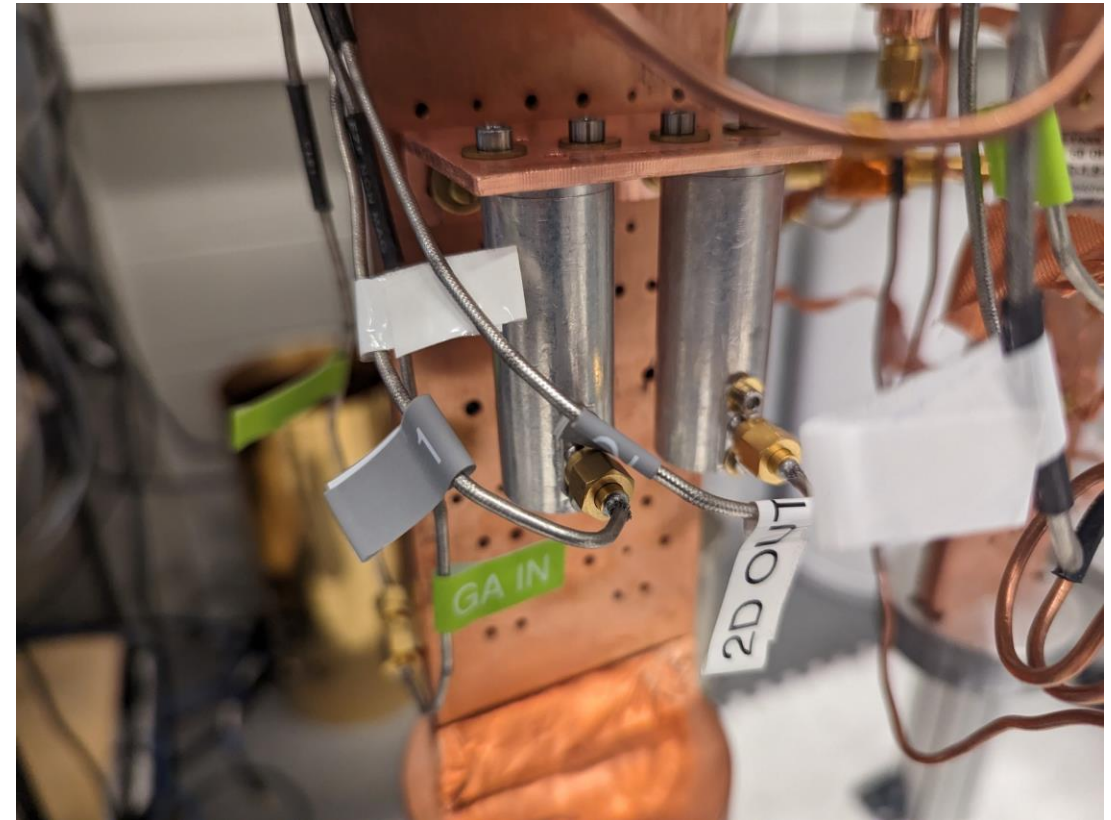


Underground Data Soon!



Future Measurements

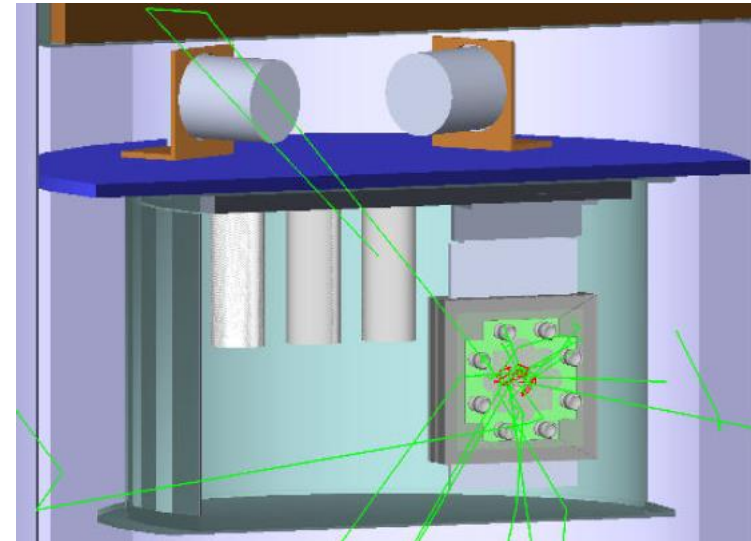
- One qubit chip + several 3D aluminum cavities
 - Study two level system losses vs. quasiparticle losses
- Two qubit chips
 - Study correlated errors across physically separated devices



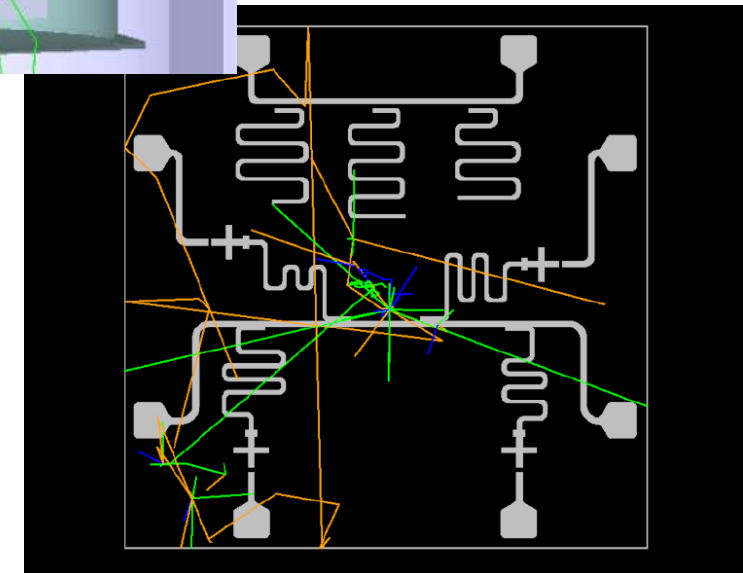
Courtesy of G. Peng

Advertisement: QUTEbits Simulations

- Background simulations using Geant4
 - Rates informed from material assays
- Sensor response studies using G4CMP
- For more see Stefan Zatschler's [parallel talk](#) in R2-3



Courtesy of S. Zatschler



Summary

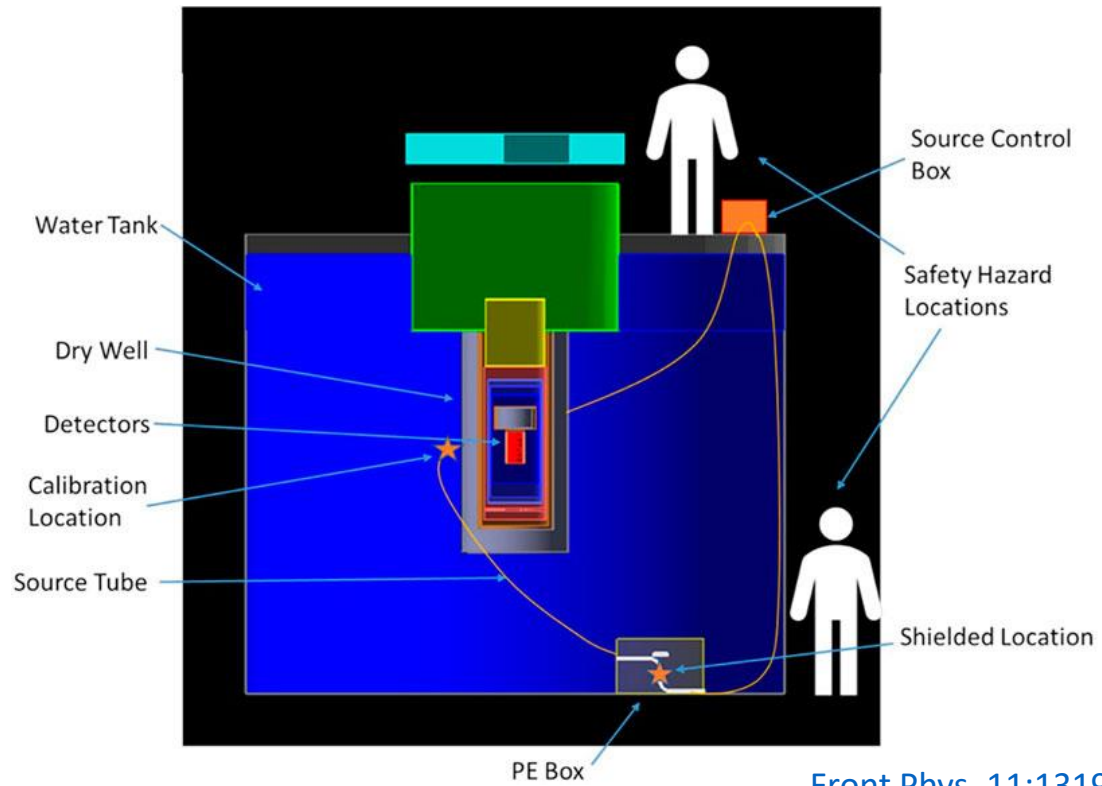
- Coherence time of superconducting qubits may be impacted by cosmic rays
- The CUTE facility at SNOLAB provides an ideal venue for testing this hypothesis
 - Opportunity for comparing devices above and below ground
 - Opportunity for testing devices in different radiation environments
- First data expected very soon!

Backup Slides

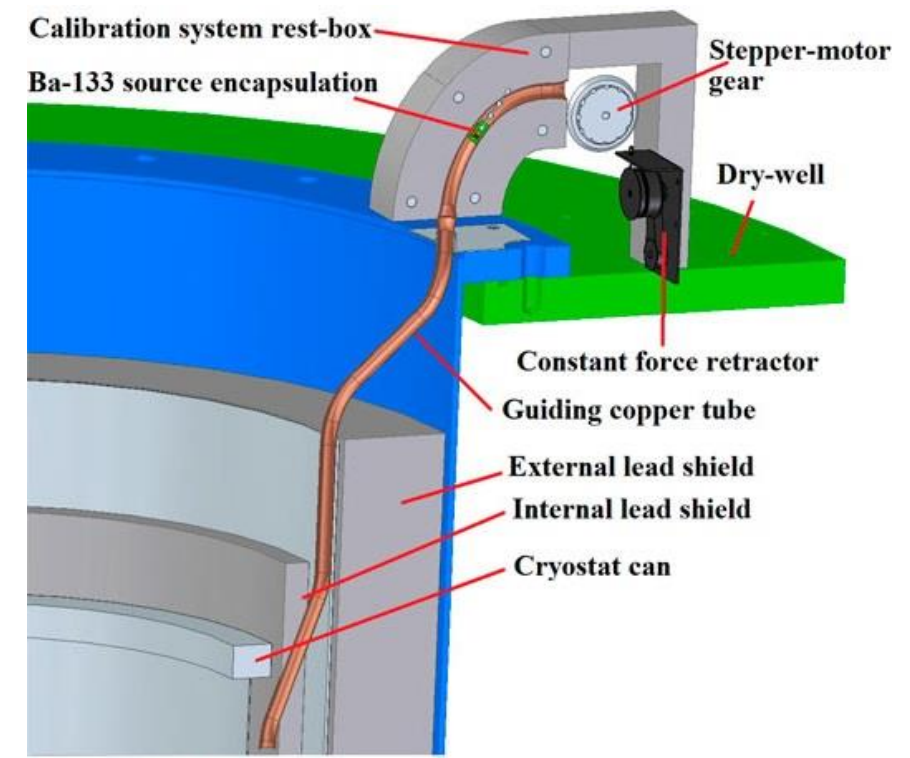
Qubit Parameters

Parameter	Q1	Q2	Q3
Designed f_{ro} (GHz)	6.07	6.22	6.36
Measured f_{ro} (GHz)	6.0831	-	6.3650
Measured f'_{ro} (GHz)	6.0823	-	6.3644
Q_e	8.733k	-	7.716k
Q_L	7.874k	-	7.044k
κ (μs^{-1})	4.85	-	5.68
Designed f_{01} (GHz)	3.126		3.683
Measured f_{01} (GHz)	3.371	-	2.916
Δ (GHz)	2.712	-	3.449
Measured f_{12} (GHz)	3.131	-	2.659
E_C/h (MHz)	240	-	257
E_J/h (GHz)	6.791	-	4.897
E_J/E_C	28.29	-	19.05
g (MHz)	65.01	-	73.87
χ (MHz)	0.151	-	0.127
$T_{Purcell}$ (ms)	0.358	-	0.384
T_1 (us)	89.42 ± 9.65	-	83.39 ± 16.23
T_2^R (us)	8.18 ± 0.98	-	-
T_2^E (us)	45.44 ± 3.83	-	35.00 ± 4.69

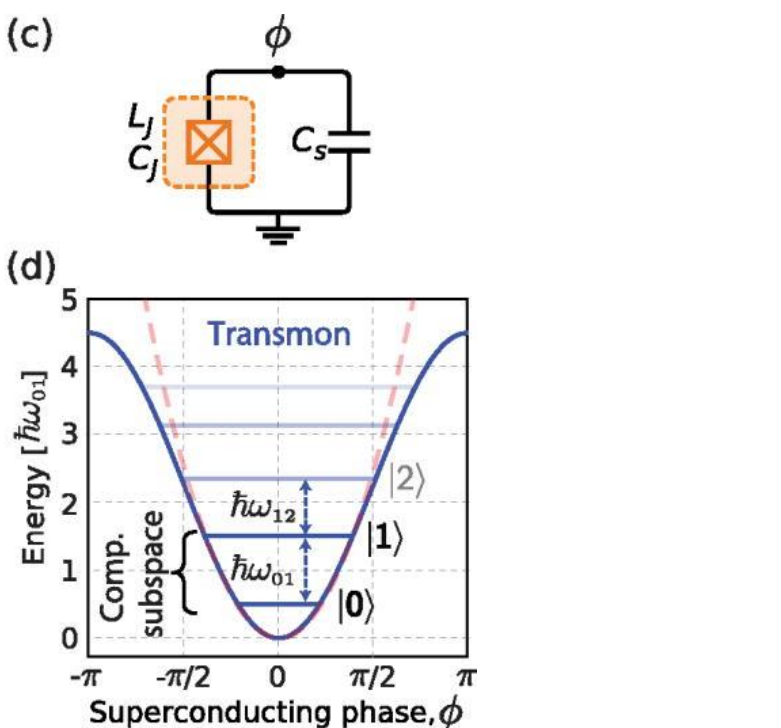
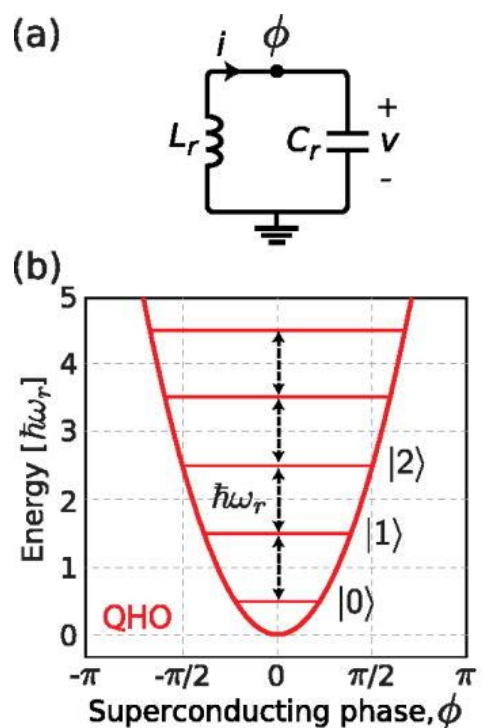
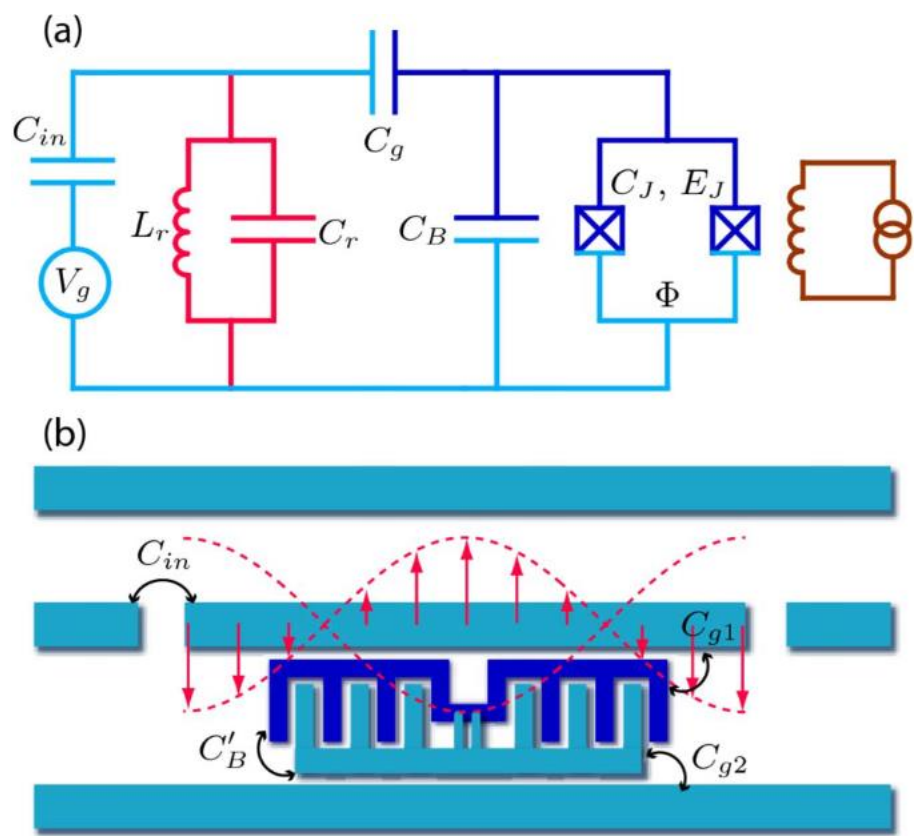
CUTE Source Locations



[Front Phys. 11:1319879 \(2023\)](#)



Transmon Qubits

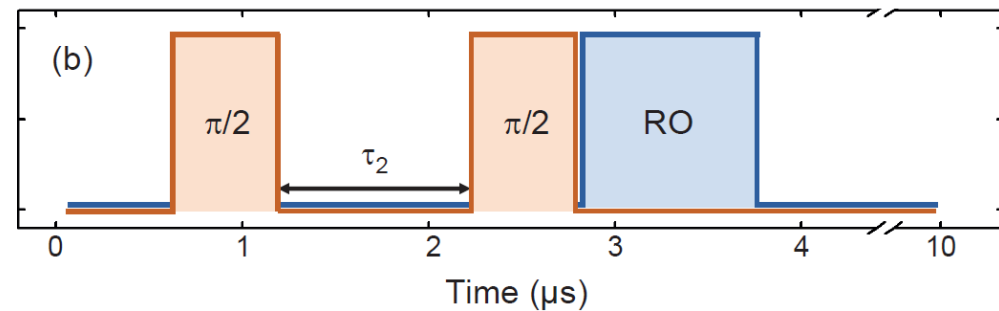
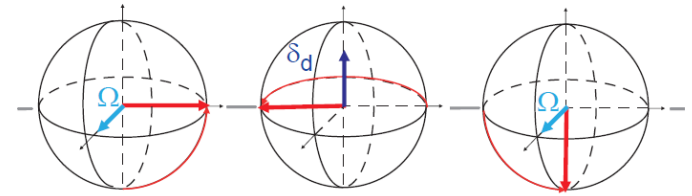


[Phys. Rev. A 76, 042319 \(2007\)](#)

[Appl. Phys. Rev. 6, 021318 \(2019\)](#)

T₂ Measurements

Ramsey (a)



Spin Echo (a)

