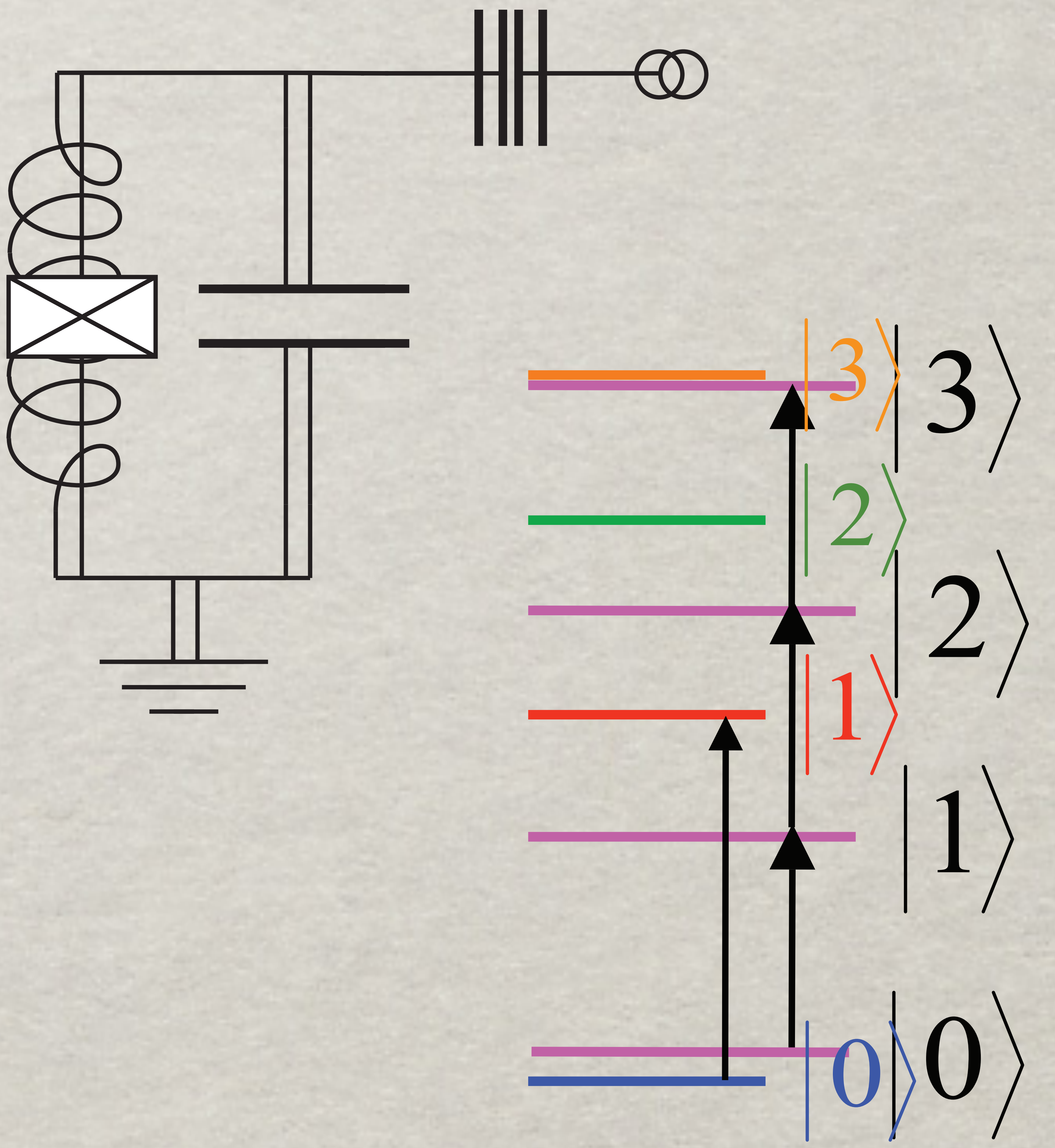
Advanced characterization and mitigation of qubit decoherence in a deep underground environment

Snolab
University of Waterloo
Chalmers University

Motivation

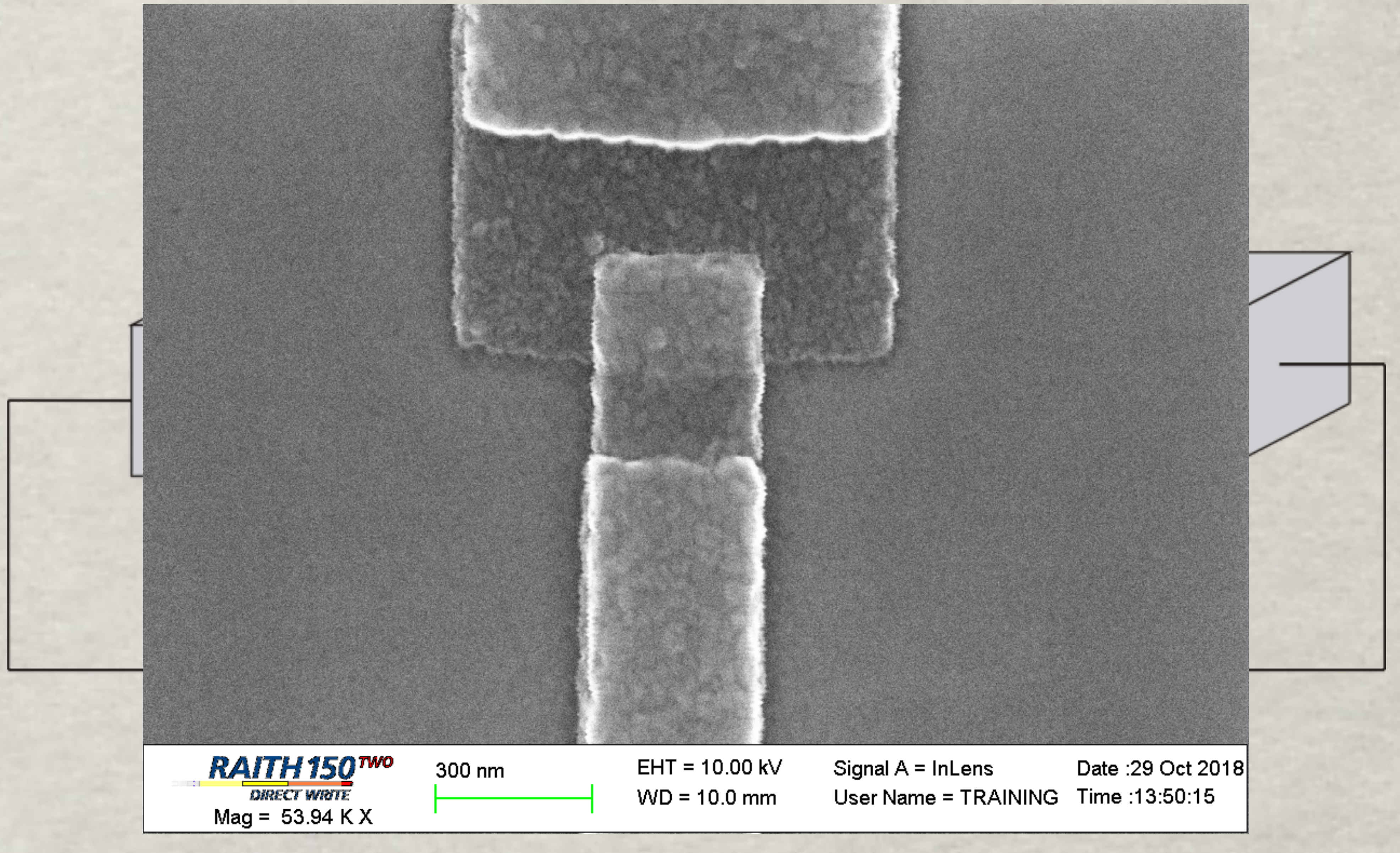
Transmon Qubits

- Quantized electrical circuit
- Harmonic oscillator is not a qubit
- Nonlinearity makes the circuit anharmonic and addressable
- Small JJ is a good nonlinear inductor



Josephson Junction

- Tunnel junction between superconductors
- The current-voltage relation for the JJ is determined by the Josephson equations
- Circuit model: a nonlinear inductor



Inductor: $$I = \frac{1}{L}\int V\,dt$$

$$I = I_c \sin\varphi$$

$$\varphi = \frac{2e}{h}\int V\,dt$$

Motivation

- Flurry of recent work showing negative impact of ionizing radiation on qubit performance
- Creation of correlated errors particularly problematic

Article

Impact of ionizing radiation on superconducting qubit coherence

https://doi.org/10.1038/s41586-020-2619-8

Received: 25 January 2020

Accepted: 5 June 2020

Published online: 26 August 2020

Antti P. Vepsäläinen[1✉], Amir H. Karamlou[1], John L. Orrell[2✉], Akshunna S. Dogra[1,4], Ben Loer[2], Francisca Vasconcelos[1], David K. Kim[3], Alexander J. Melville[3], Bethany M. Niedzielski[3], Jonilyn L. Yoder[3], Simon Gustavsson[1], Joseph A. Formaggio[1], Brent A. VanDevender[2] & William D. Oliver[1,3]

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Correlated charge noise and relaxation errors in superconducting qubits

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The central challenge in building a quantum computer is error correction. Unlike

Motivation

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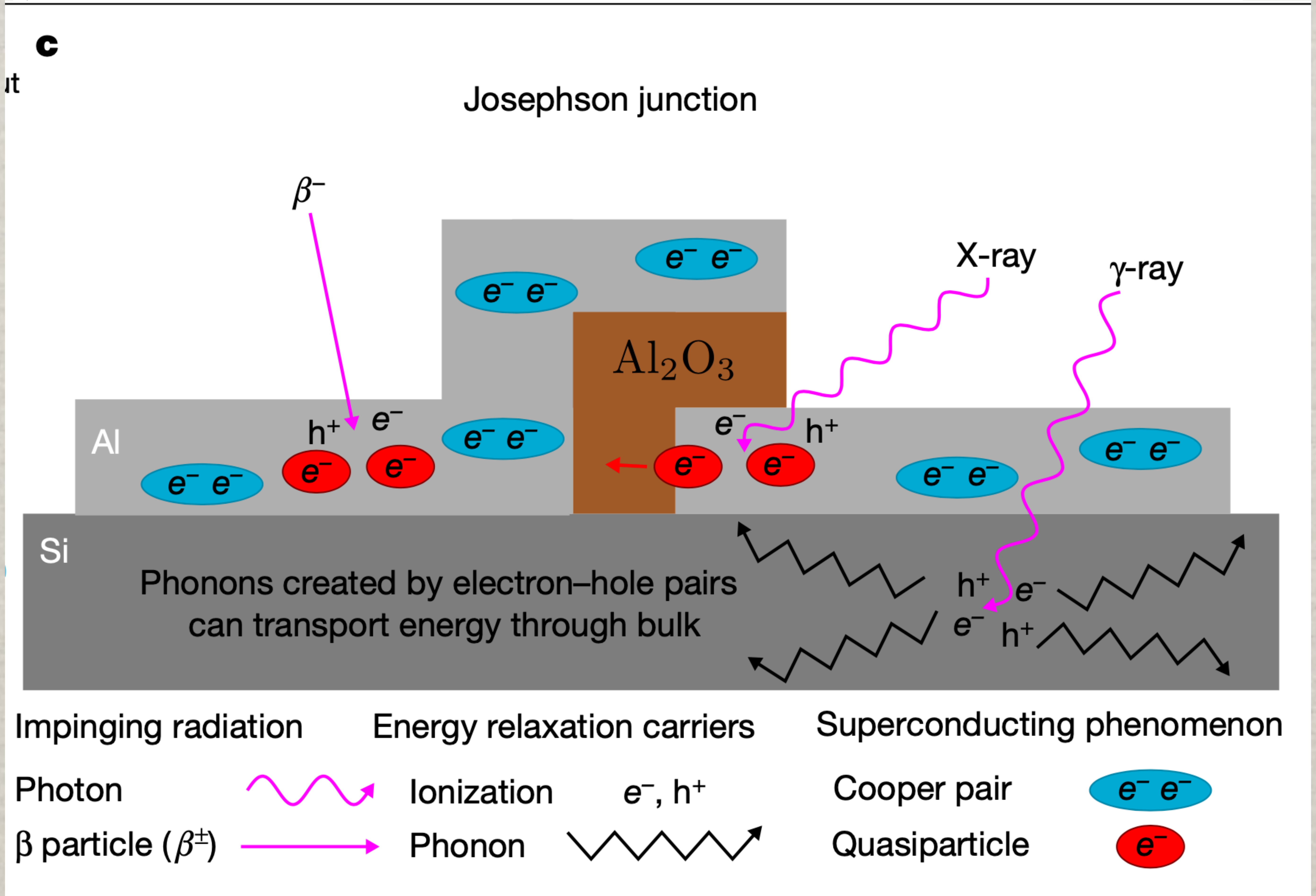
Impact of ionizing radiation on superconducting qubit coherence



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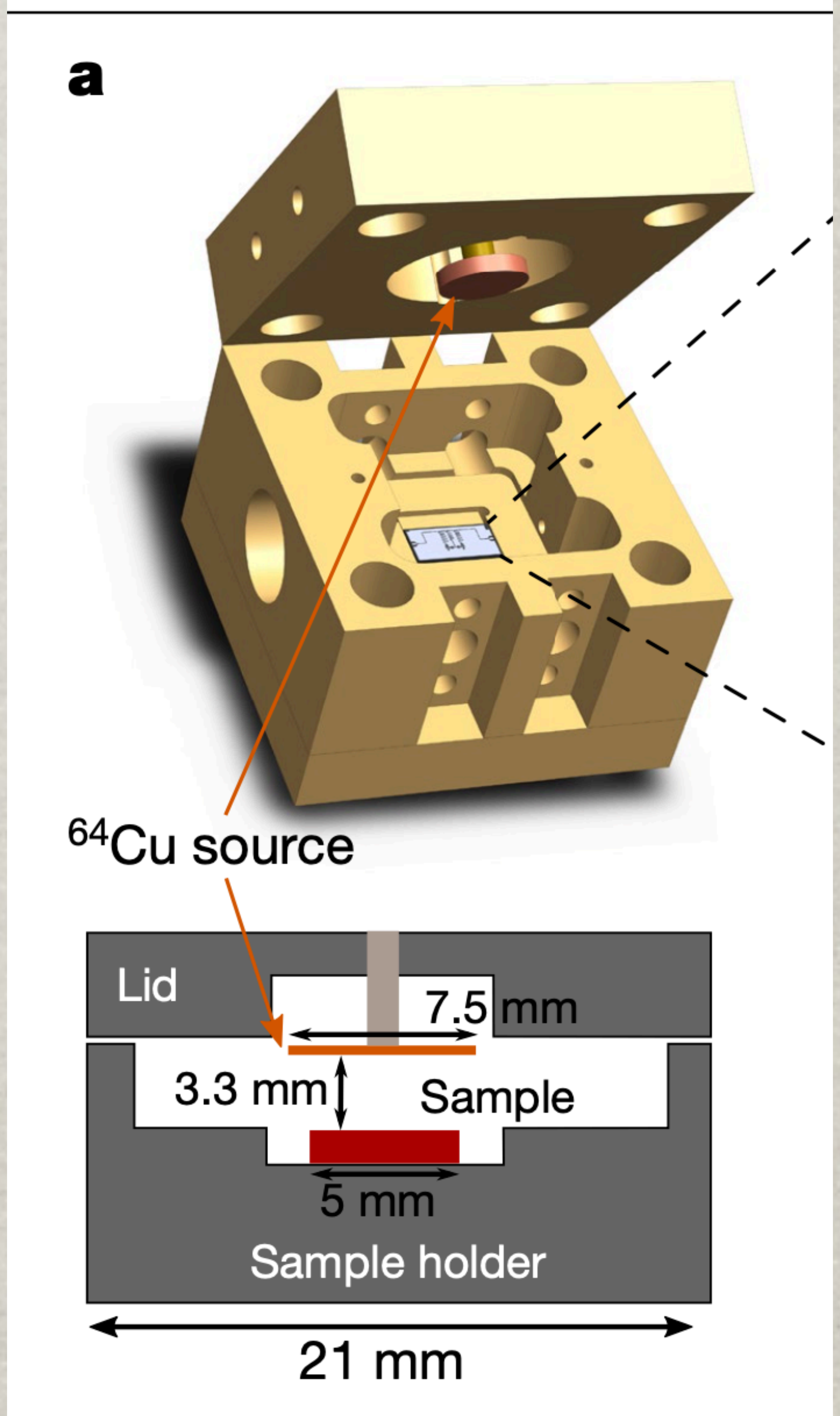
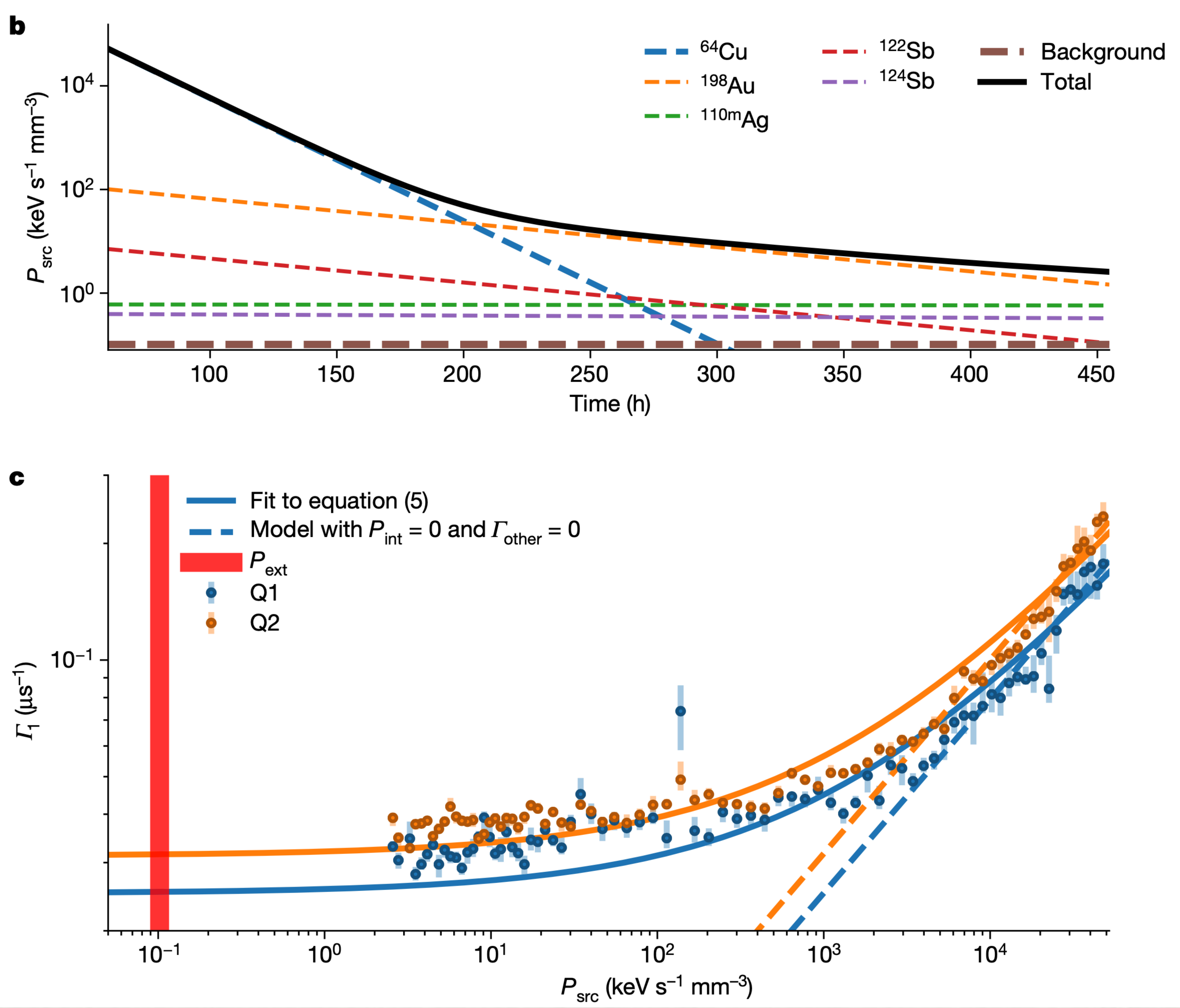
- Use radioactive Cu source (made at on-campus reactor!) to measure qubit coherence during decay



Impact On Coherence



- Clear dependence of qubit coherence time (lifetime) on radiation level

Motivation

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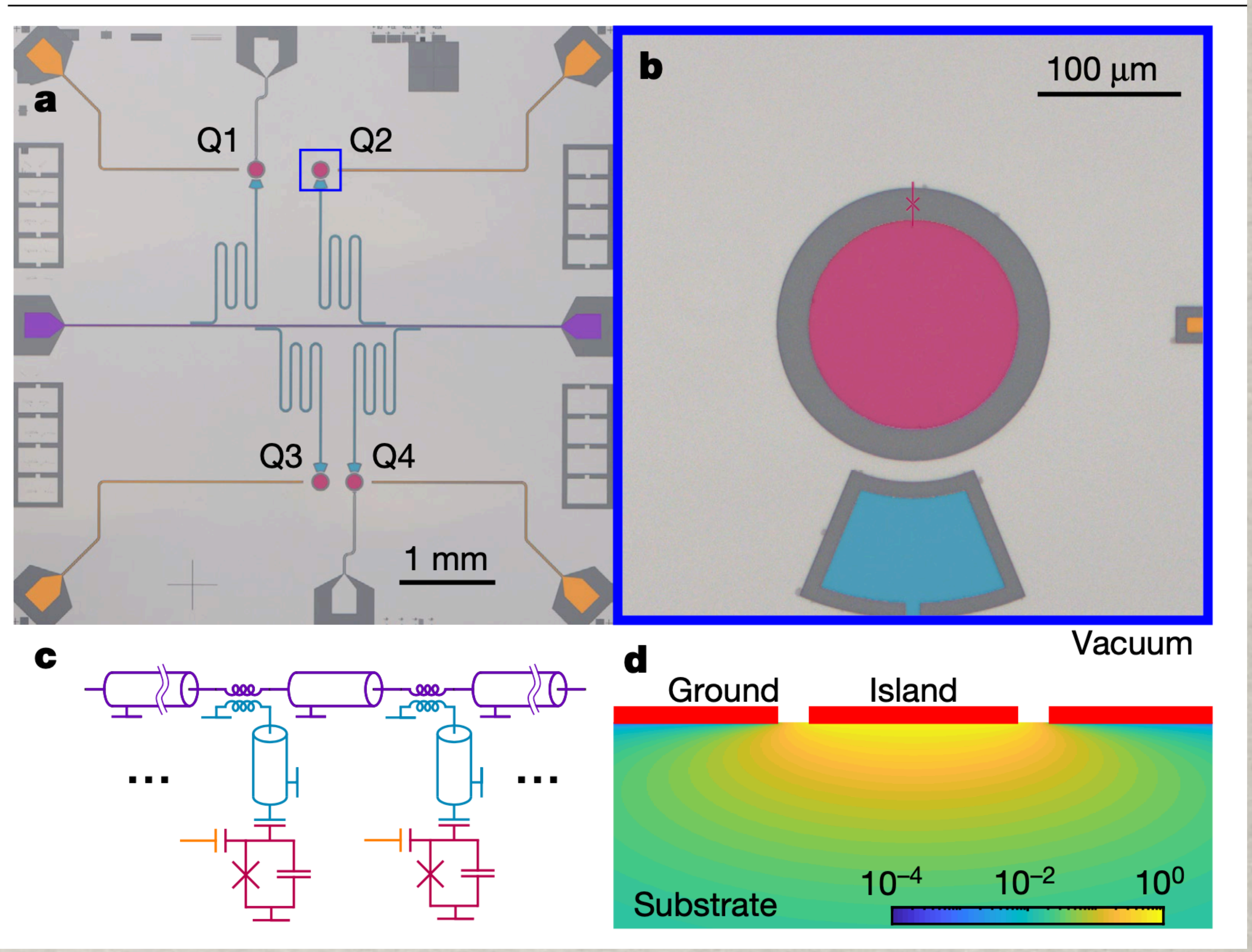
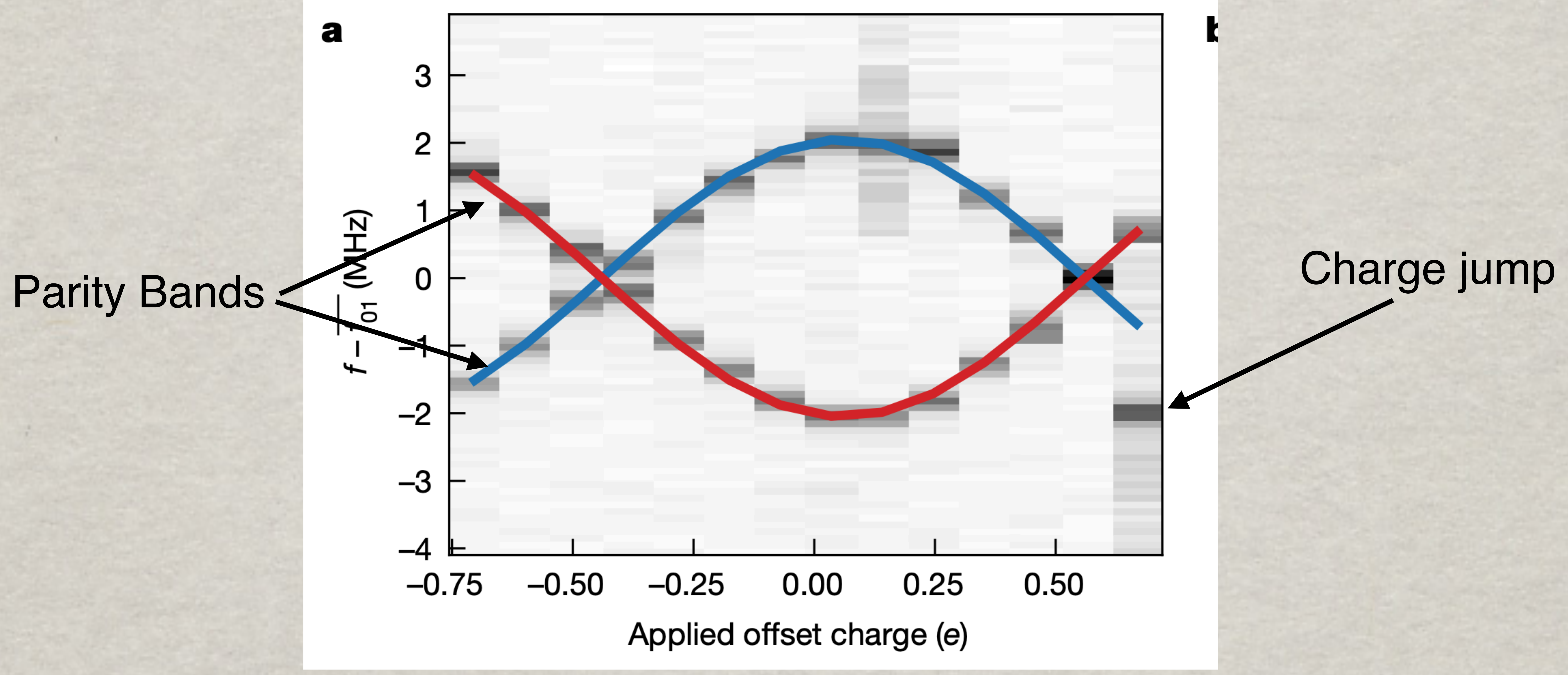
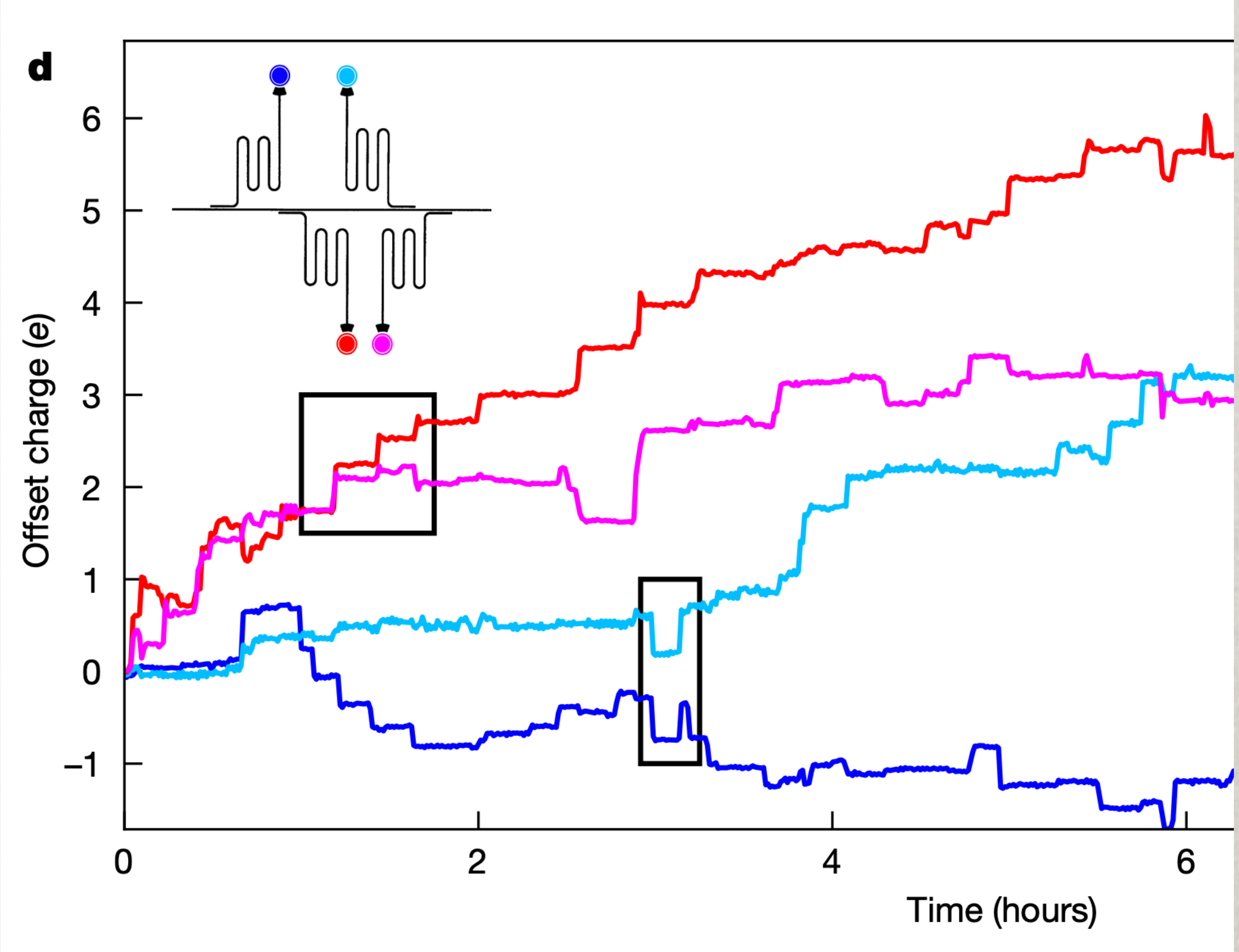


QP and Charge Noise



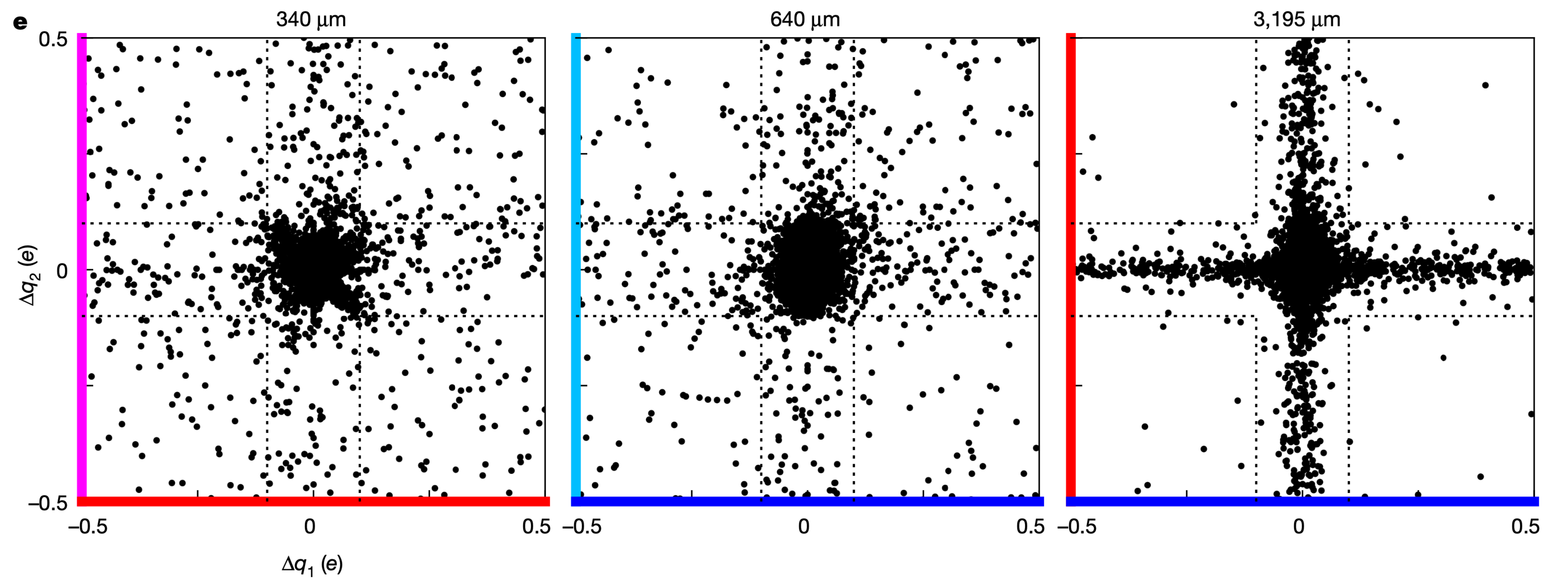
- QP poisoning and charge noise are issues for high-precision transmons
- Red and blue bands reflect switching of QP parity
- Discrete charge jumps also observed (on right edge)

Correlated Noise



- Measuring offset charge over long times
- Correlated noise also appears
- Correlated noise breaks most quantum-error correction

Correlated Noise



- Correlations depend on distance, suggesting substrate is involved

Motivation

nature physics

ARTICLES

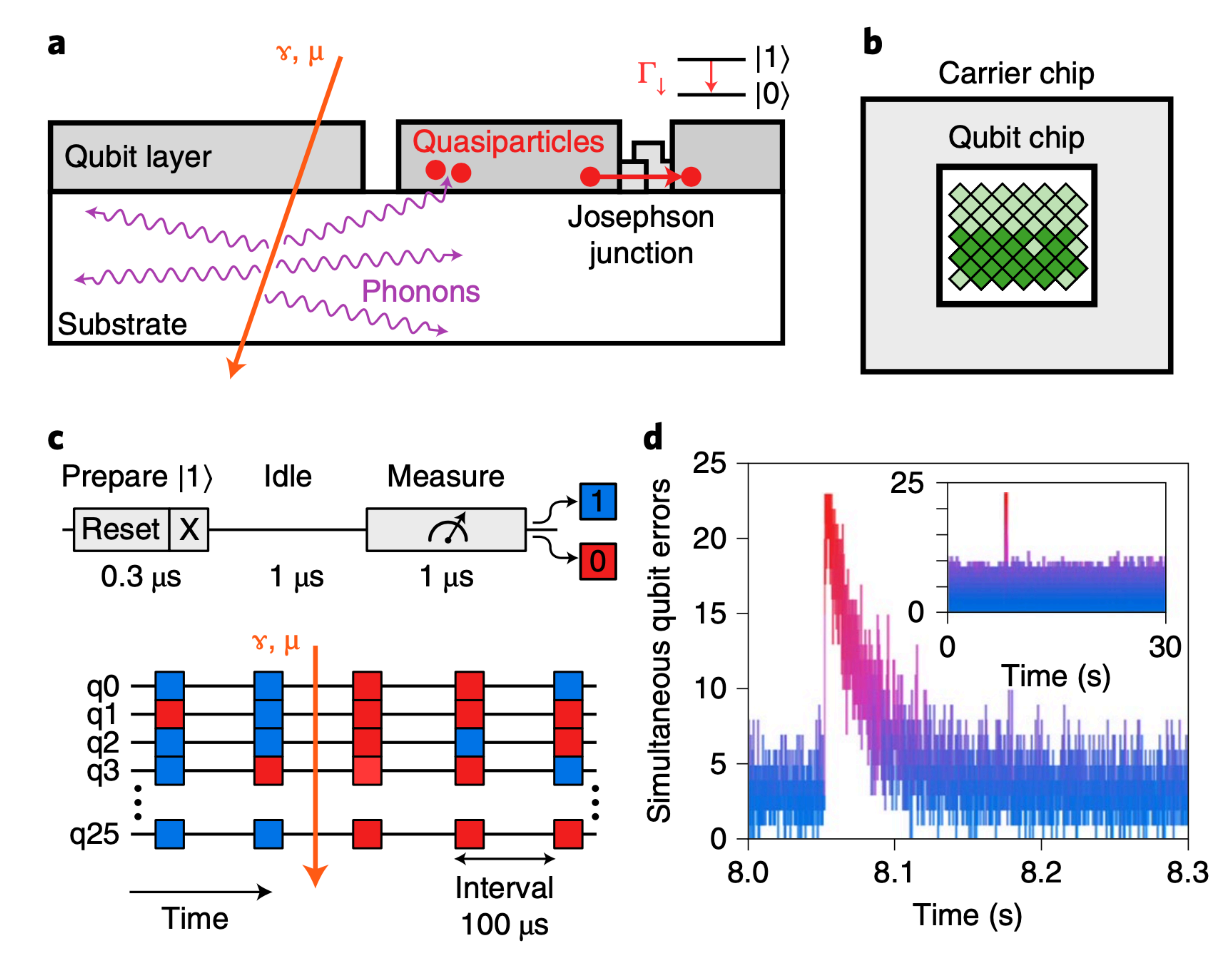
https://doi.org/10.1038/s41567-021-01432-8

Check for updates

Resolving catastrophic error bursts from cosmic rays in large arrays of superconducting qubits

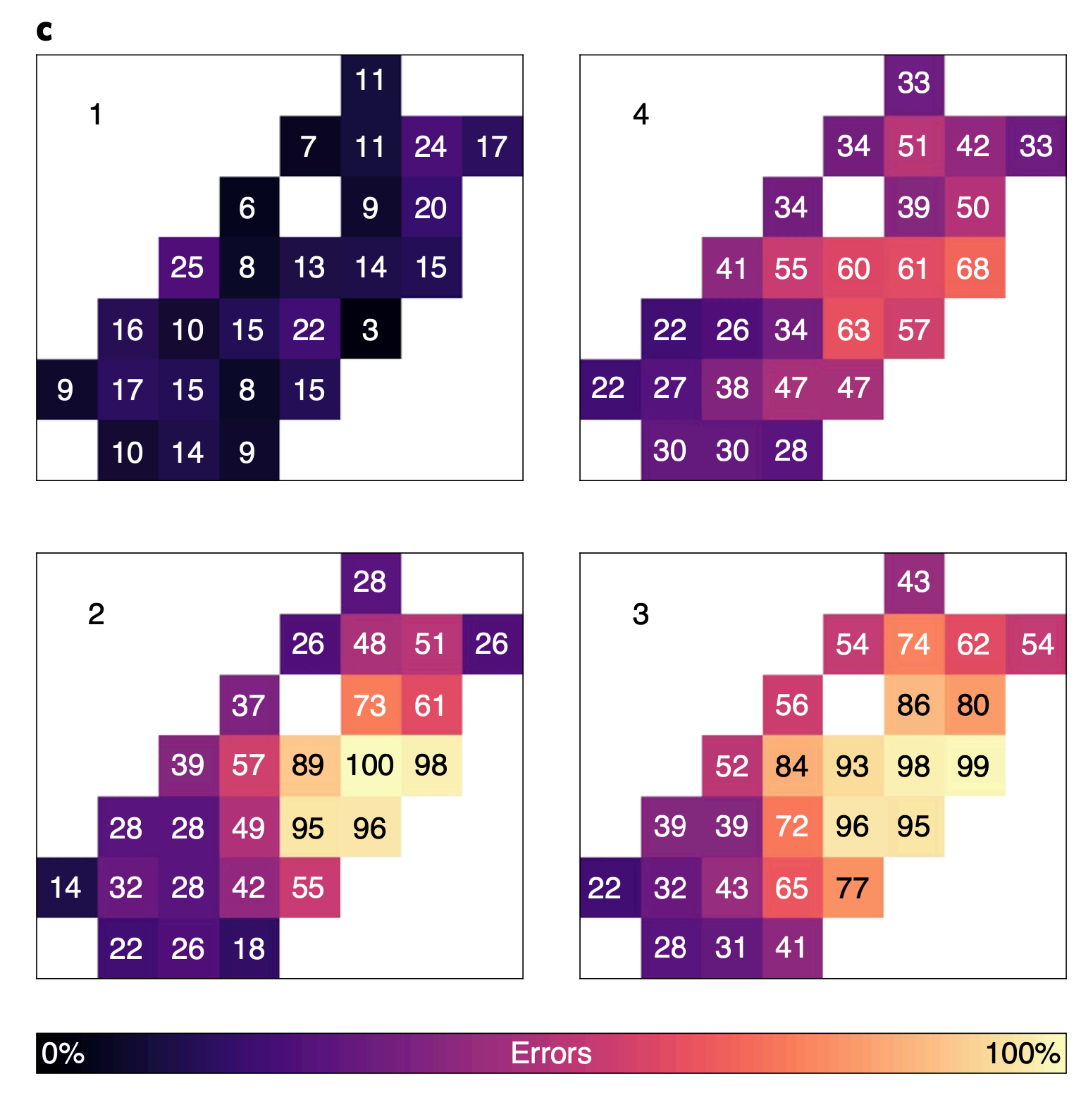
Matt McEwen[1,2], Lara Faoro[3], Kunal Arya[2], Andrew Dunsworth[2], Trent Huang[2], Seon Kim[2], Brian Burkett[2], Austin Fowler[2], Frank Arute[2], Joseph C. Bardin[2,4], Andreas Bengtsson[2], Alexander Bilmes[2], Bob B. Buckley[2], Nicholas Bushnell[2], Zijun Chen[2], Roberto Collins[2], Sean Demura[2], Alan R. Derk[2], Catherine Erickson[2], Marissa Giustina[2], Sean D. Harrington[2], Sabrina Hong[2], Evan Jeffrey[2], Julian Kelly[2], Paul V. Klimov[2], Fedor Kostritsa[2], Pavel Laptev[2], Aditya Locharla[2], Xiao Mi[2], Kevin C. Miao[2], Shirin Montazeri[2], Josh Mutus[2], Ofer Naaman[2], Matthew Neeley[2], Charles Neill[2], Alex Opremcak[2], Chris Quintana[2], Nicholas Redd[2], Pedram Roushan[2], Daniel Sank[2], Kevin J. Satzinger[2], Vladimir Shvarts[2], Theodore White[2], Z. Jamie Yao[2], Ping Yeh[2], Juhwan Yoo[2], Yu Chen[2], Vadim Smelyanskiy[5], John M. Martinis[1], Hartmut Neven[5], Anthony Megrant[2], Lev Ioffe[2] and Rami Barends[2,6] ✉

QPU Correlations



- Large bursts of correlated errors observed in Google QPUs

QPU Correlations



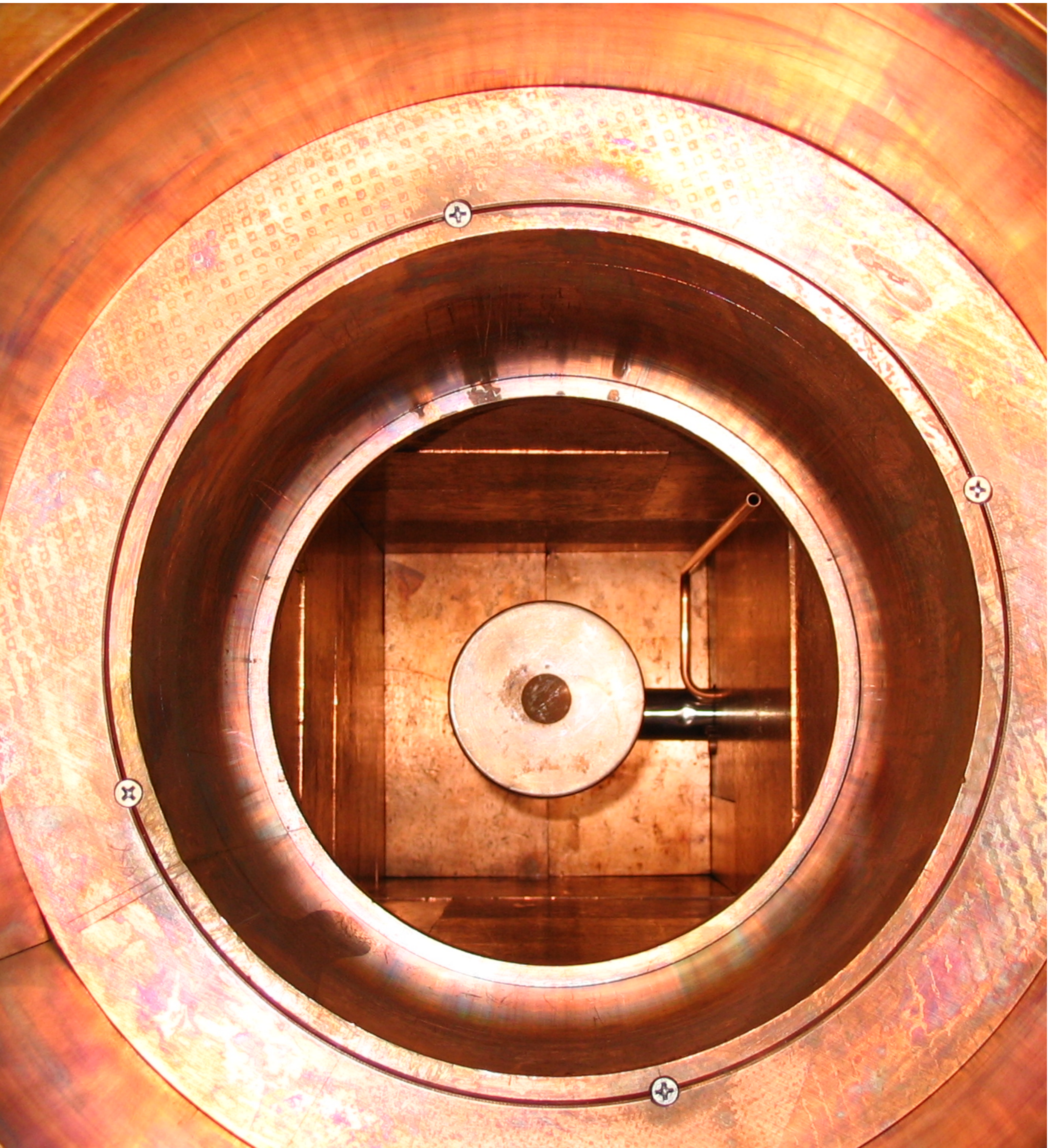
- Spatial evolution of errors also clearly observed

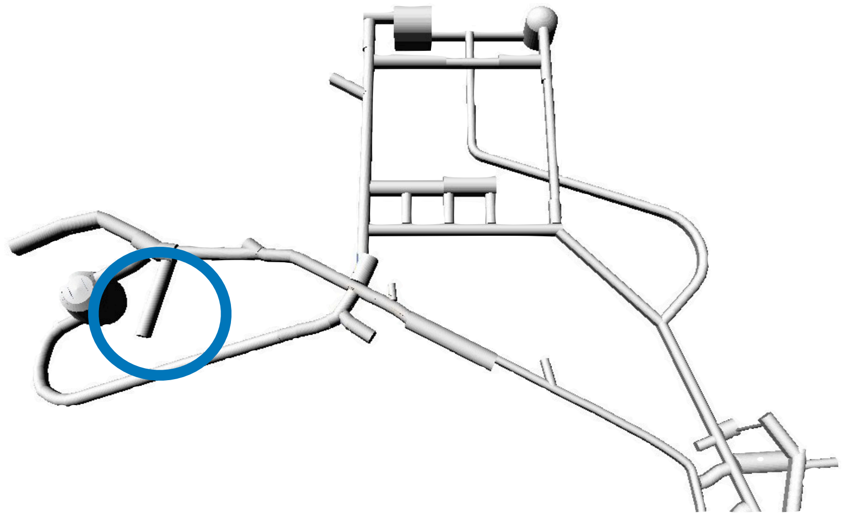
The Project

Project Goals

- Quantifying the effect of radiation on qubit decoherence including correlated errors
- Identifying sources of decoherence through alternative sensors
- Mitigating the effects of radiation on superconducting qubits

SNOLAB Low-Background Screening Capabilities





HPGe Detectors:

PGT Coaxial Detector , Canberra Coaxial Detector (**Lively**), Canberra **Well** Detector, Eurisys Mesures Coaxial Detector (**Vue Des Alpes**), Canberra Coaxial Detector (**Gopher**), Canberra Dual HPGe (**CTBT**)

Alpha Counting:

XIA UltraLo-1800

Radon Emanation Measurements:

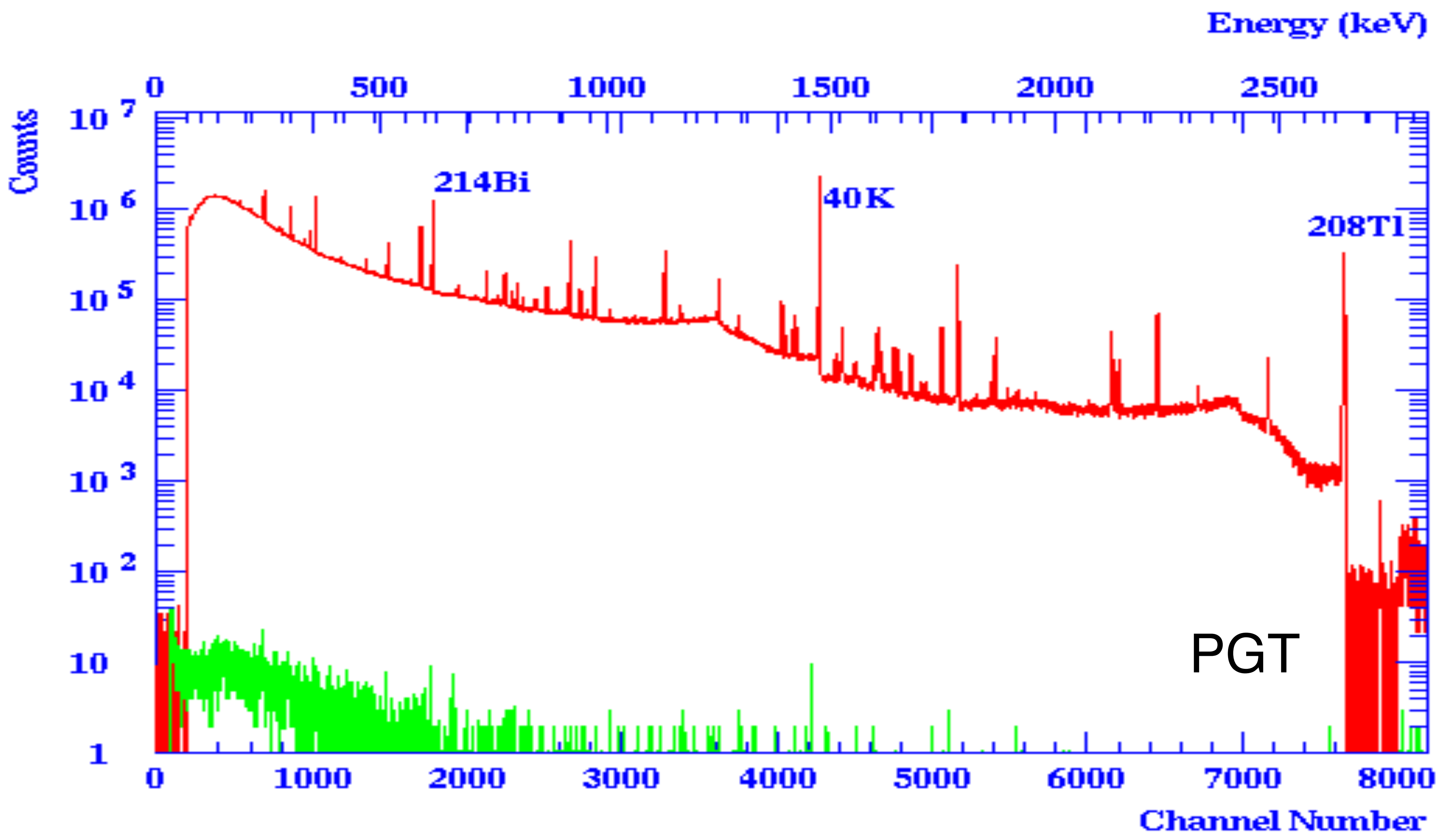
Electrostatic Counter (**ESC**)

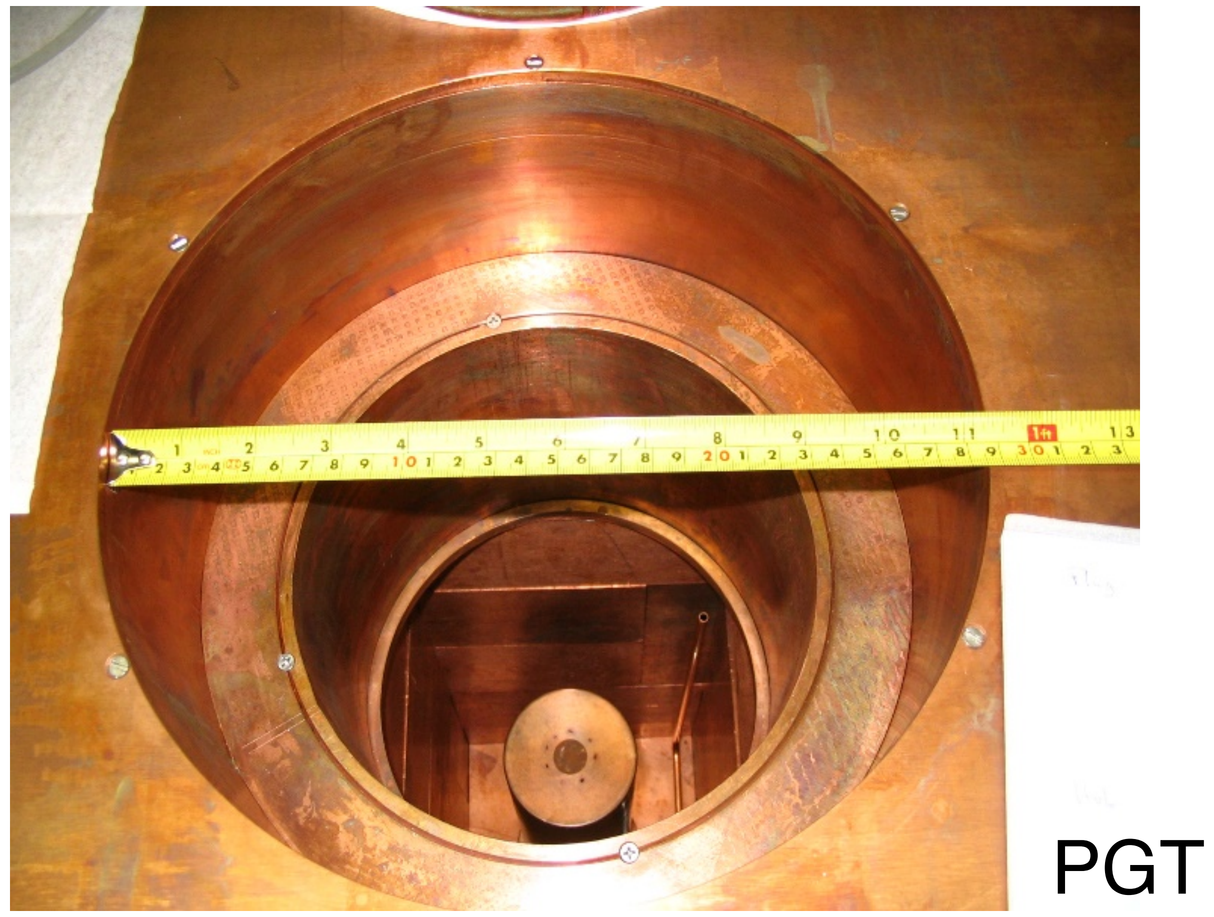
Radon Emanation Studies using Bronze and Xeolite/Chromosorb traps

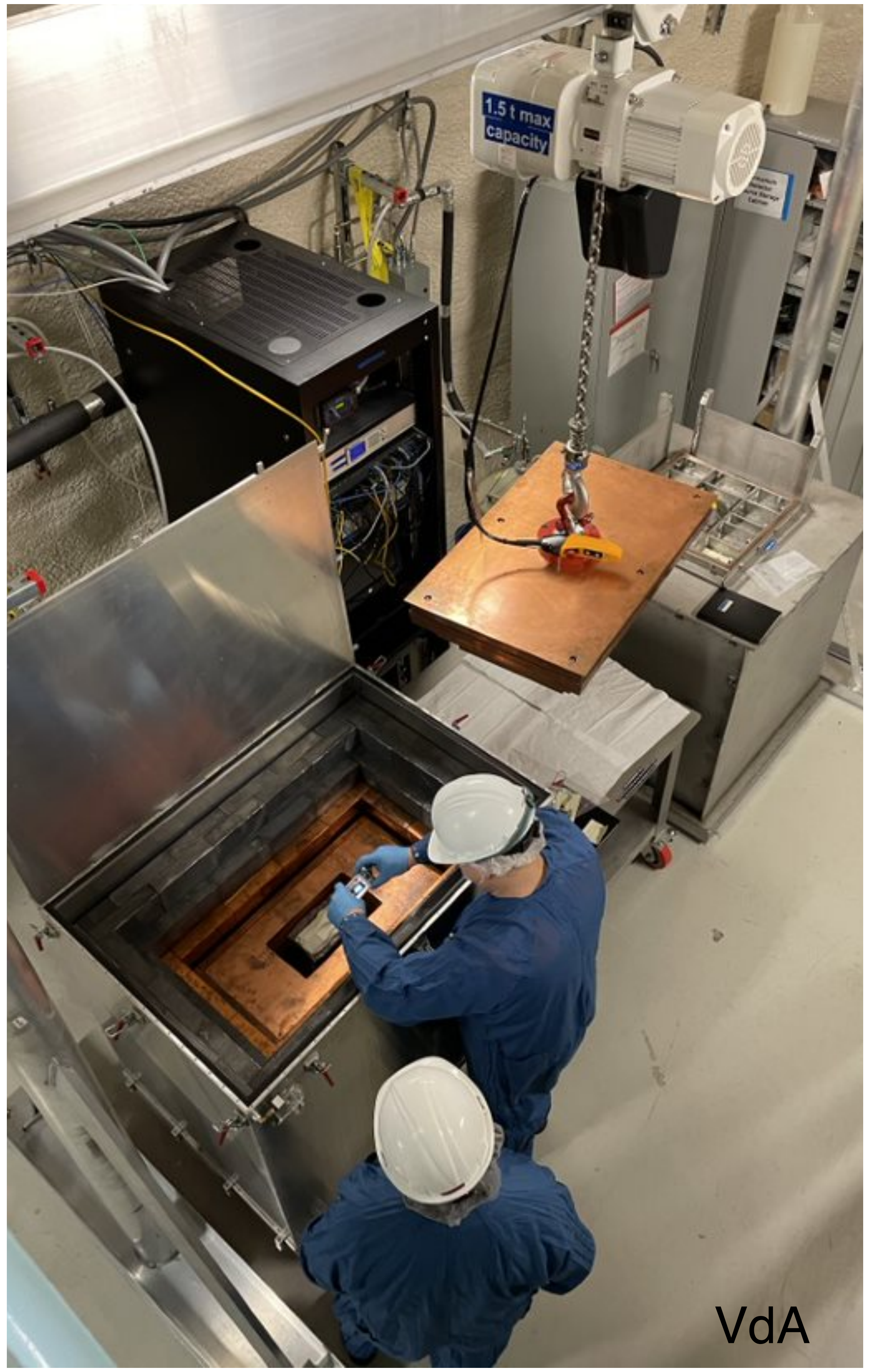
Radon Board on Water System

SNOLAB HPGe Detectors

https://www.snolab.ca/users/services/gamma-assay/assay_request_form.html







Preliminary Characterization

- Characterizing typical microwave equipment for CUTE upgrade

SNOLAB Measurements

no MC efficiency correction included *

Preliminary

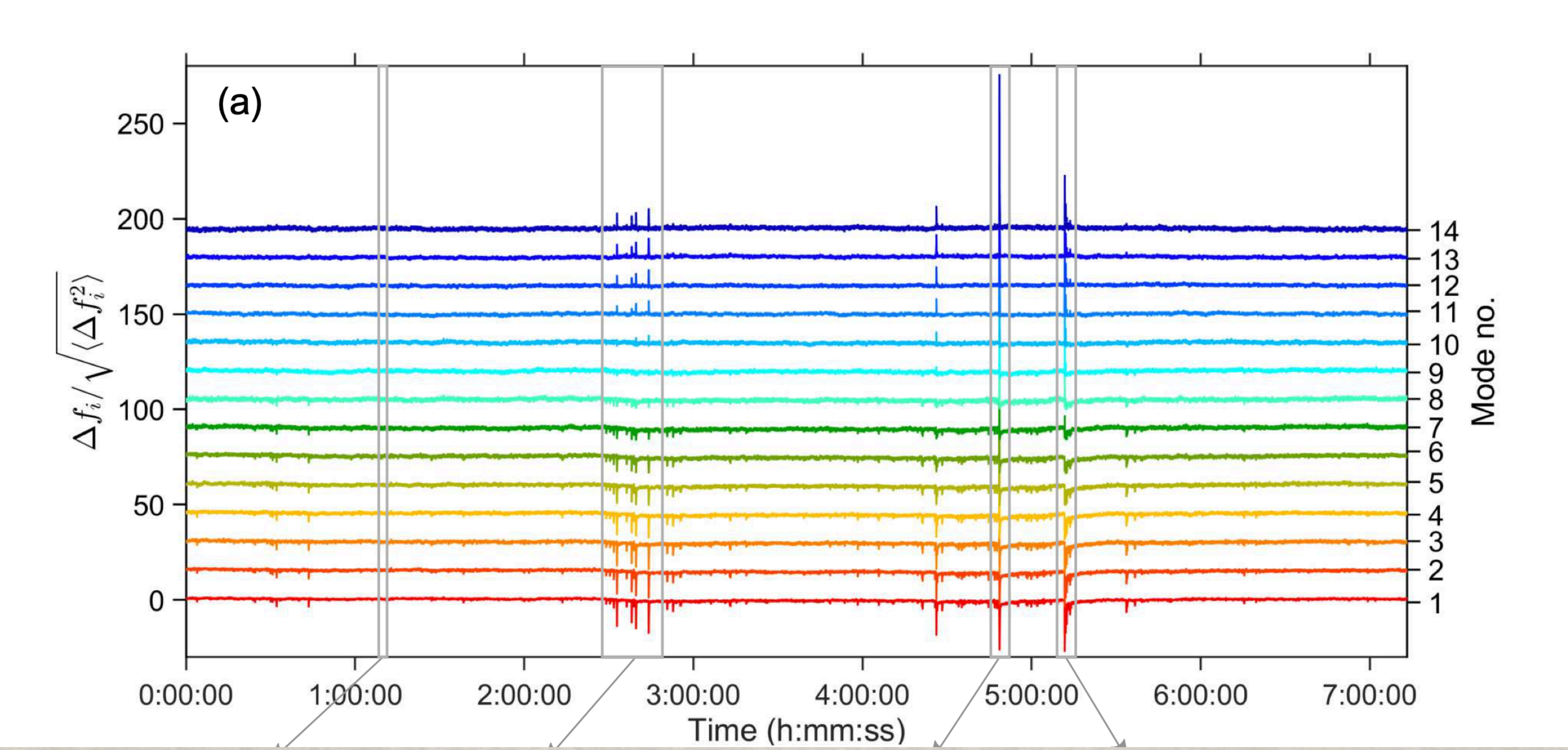
	From	Mass	Acquisition 2023	U 238 bottom (mBq/kg)	U238 top (mBq/kg)	U235 (mBq/kg)	Th232 (mBq/kg)	K40 (mBq/kg)	Cs137 (mBq/kg)	Co60 (mBq/kg)	Pb210 (mBq/kg)
PCB (used)	Waterloo	10g 5units	10.02->17.02	270.4+-18.2	419.3+-94.7	15.2+-2.7	220.5+-18.0	[illegible]	<39.7	9.7+-15.5	1610.1+-717.7
PCB (new)	Waterloo	10.7g 5units	17.02->24.02	241.6+-16.4	459.1+-83.6	11.7+-2.5	[illegible]	[illegible]	<40.5	<25.2	<984.9
* Al Pellets (new) Kurt-J Lesker (99.999% Pure)	Waterloo	4.3g	24.02->03.03	<16.4	<1217.7	<7.5	[illegible]	<1081.0	<98.1	<15.3	<920.5
* Al Slugs (new) Alfa Aeser Puratonics (99.999% Pure)	Waterloo	1.9g	03.03->17.03	<22.4	[illegible]	[illegible]	<21.3	26139.0+-1413.0	<232.5	<46.8	<1835
* Ti Pellets (new) Kurt-J Lesker (99.999% Pure)	Waterloo	2.7g	17.03->28.03	25.2+-23.2	[illegible]	5.4+-4.7	<24.0	<1131.0	<177.8	<69.4	<1250.0
* Tin plated PCB	Chalmers	4.8g 13units	28.03->04.04	[illegible]	6385.0+-479.5	305.6+-17.2	7029.0+-275.9	8761.5+-2024.0	<85.2	<80.2	1396.7+-760.2
Al (used) Old Melts Plussys E-Beam	Waterloo	139g 5units	24.02->03.03	<3.9	<85.7	<2.8	9.5+-3.6	<26.9	<1.7	<0.7	NA
* Al (used) Melts Plussys E-Beam	Waterloo	24g 2units	03.03->14.03	<8.0	<911.6	<13.6	191.0+-23.5	214.9+-190.9	<12.1	<7.0	NA
* Copper Piece	Chalmers	94g	20.03->28.03	<5.1	<174.5	2.6+-3.4	<9.4	<130.2	<11.8	<1.6	NA

Project Goals

- Quantifying the effect of radiation on qubit decoherence including correlated errors
  - Establish baseline measurements of coherence times between multiple above ground facilities (Chalmers and IQC) and then move underground
  - Distinguish between cosmic rays and other forms of radiation
  - Calibrated measurements of effects of radiation starting from ultralow background

Project Goals

- Identifying sources of decoherence through alternative sensors
  - Radiation can excite multiple baths that influence qubits (qps, phonons, TLS)
  - Use different sensor to disentangle effects (CPB, resonators, SAWs)



Project Goals

- Mitigating effects of radiation on qubits
  - Once particular sources of coupling are established, work to find mitigation strategies (other than a deep mine)
  - Alternative fabrication strategies and innovative design

npj Quantum Information

www.nature.com/npjqi

ARTICLE OPEN

Check for updates

Saving superconducting quantum processors from decay and correlated errors generated by gamma and cosmic rays

John M. Martinis[1]✉

The Team

The Team

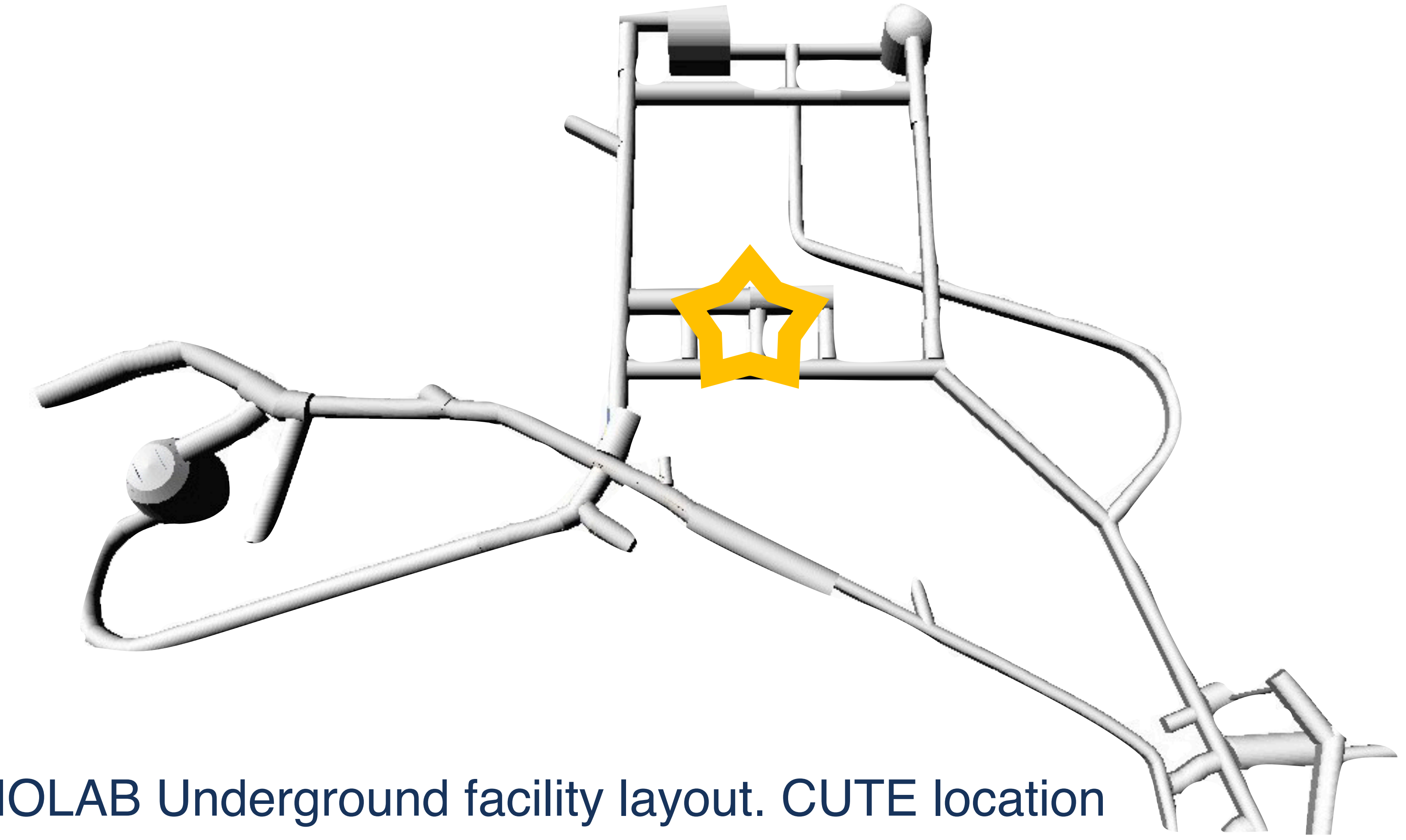
- Snolab (original the Sudbury Neutrino Observatory)
  - Deep underground science facility in Sudbury, Ontario, Canada near the northern shore of Lake Huron
- Institute for Quantum Computing at the University of Waterloo
  - Major research university in Waterloo, Ontario, Canada about 90 km outside of Toronto
- Chalmers University of Technology
  - Major research university in Gothenburg, Sweden, the home of Volvo

Underground at SNOLAB

Rock shield: 2 km underground

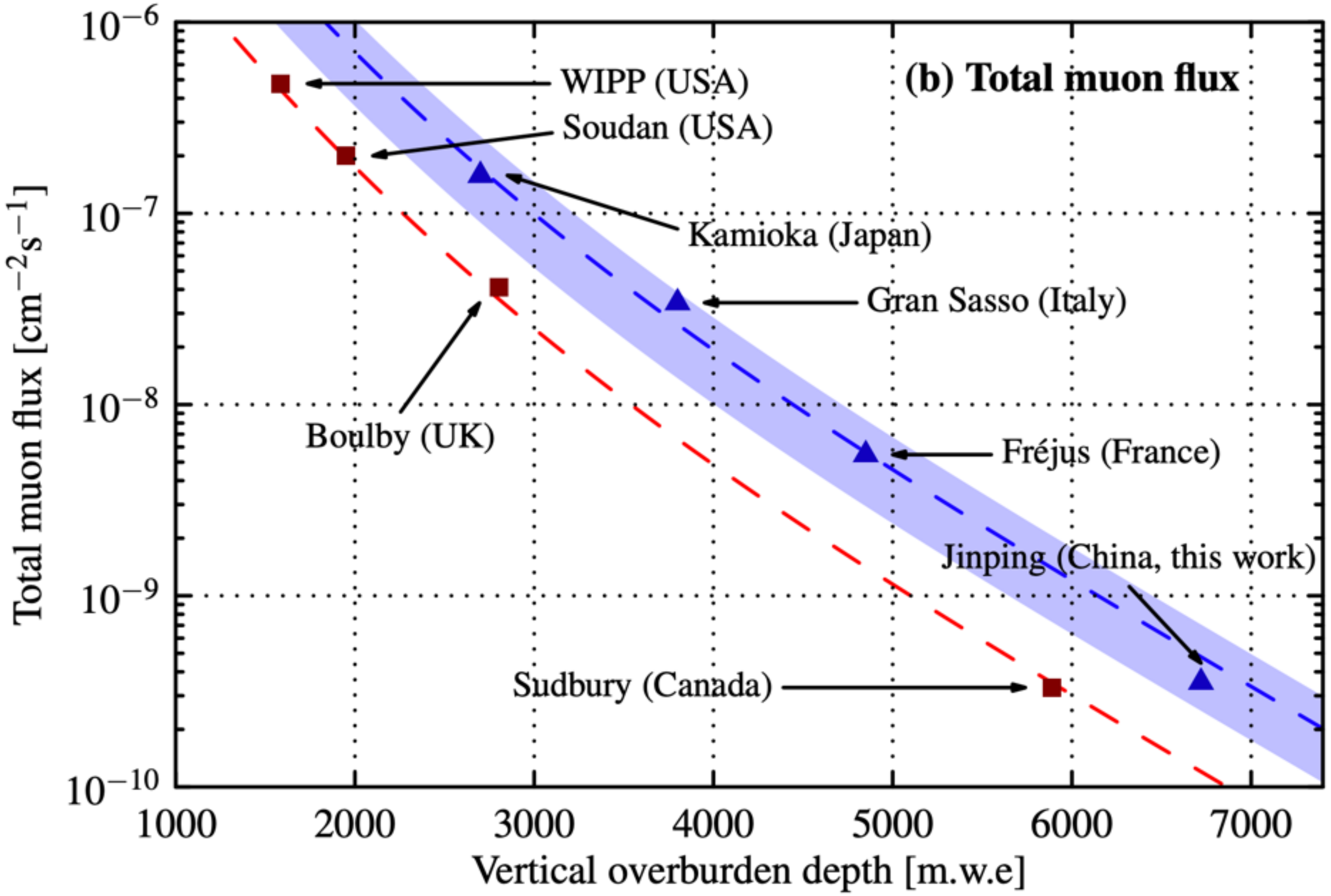
SNOLAB has the lowest muon fluxes available

Cleanroom 2000class throughout the underground facility



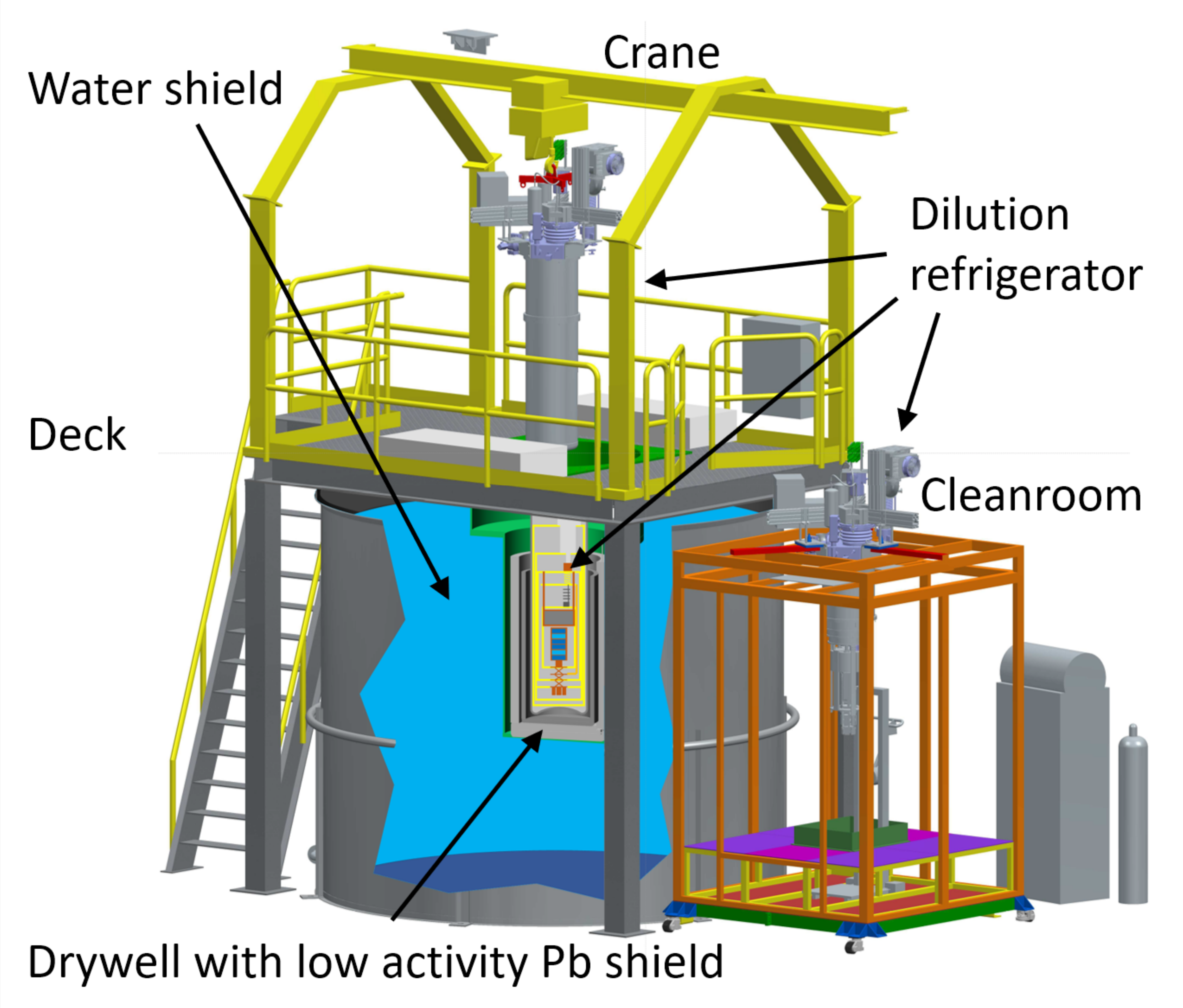
SNOLAB Underground facility layout. CUTE location

Guo et al., arXiv:2007.15925v2



S.Scorza - May 8, 2023

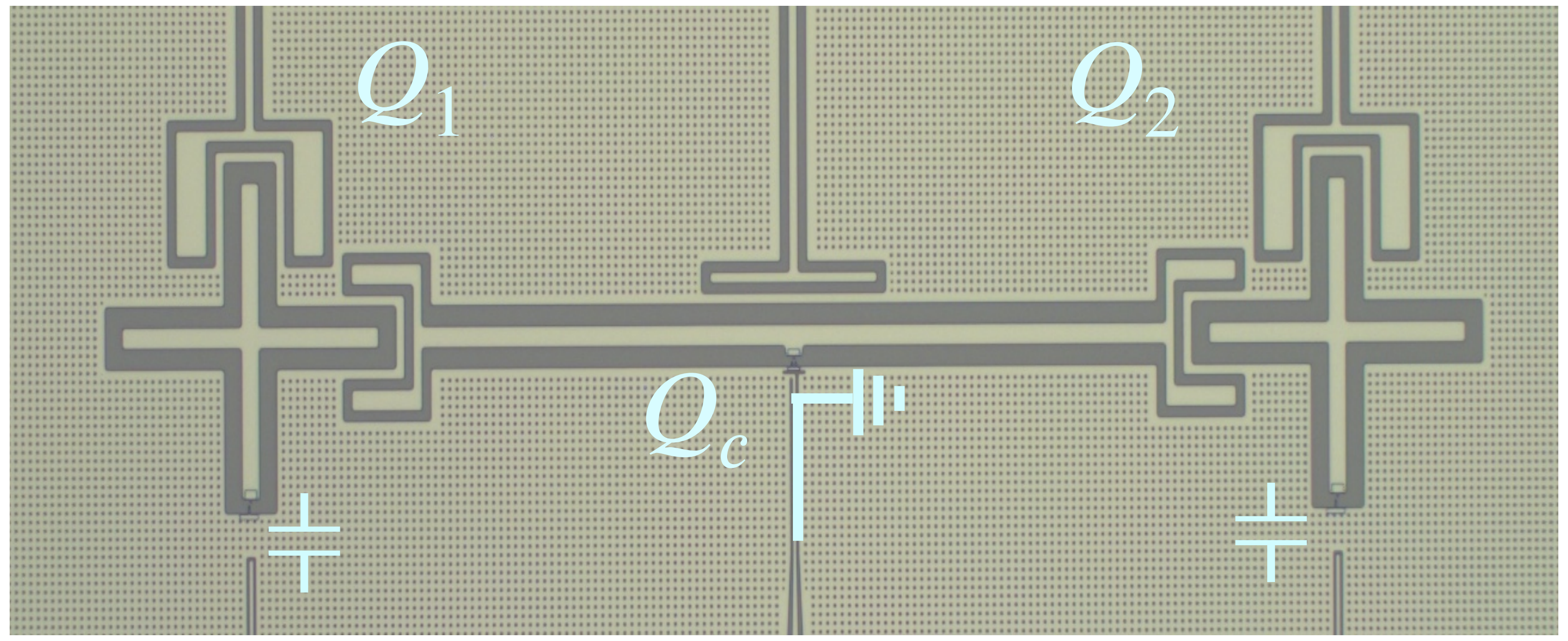
Facility Overview



Courtesy of CUTE team

Chalmers team capabilities

High quality qubits

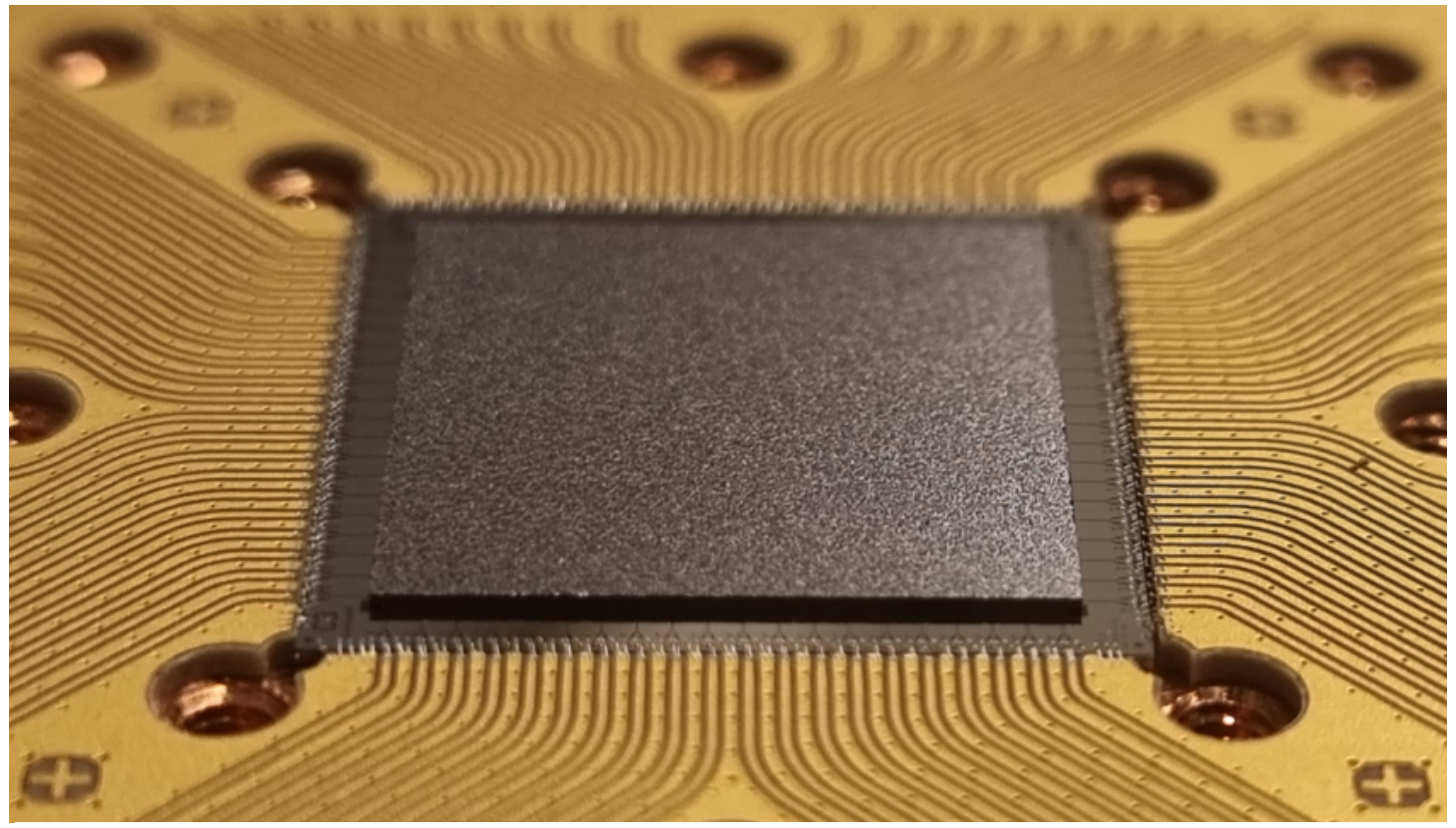


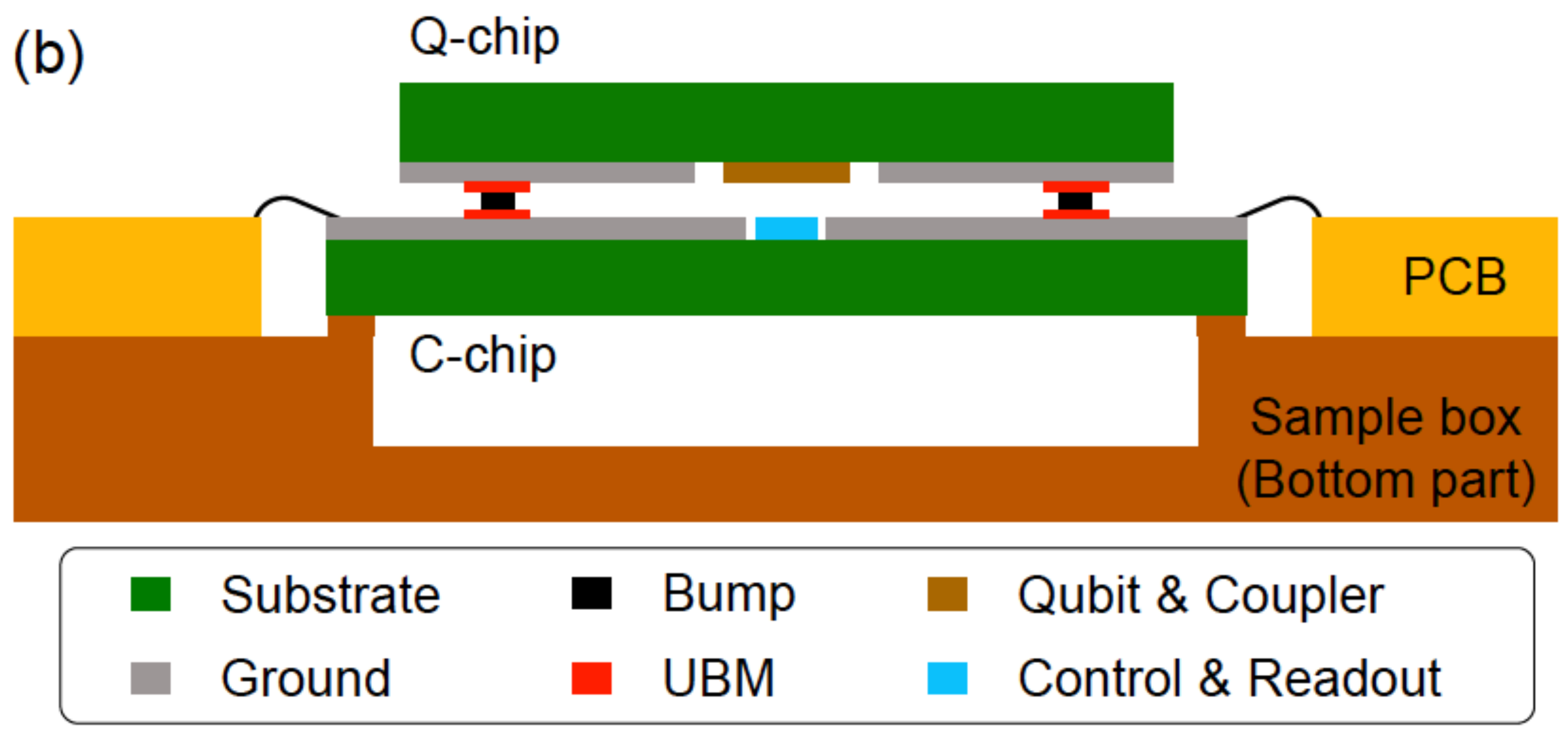
Decoherence times: T1≈T2≈100 µs
Single-qubit gate fidelity : 99.95%
Two qubit fidelity : 98.8%
Residual population: < 0.3 %

SC resonators with 1M internal Q

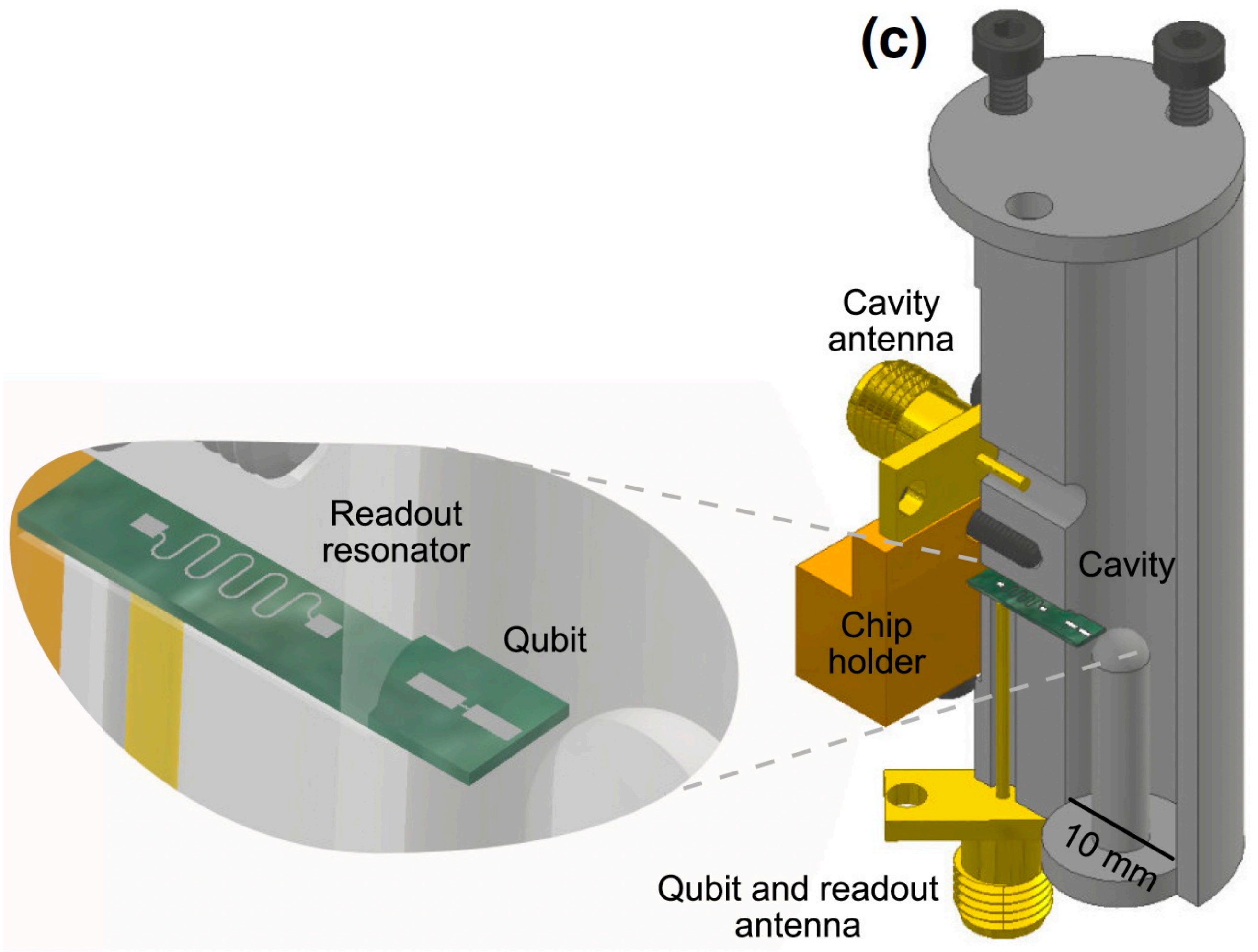
3D-integration

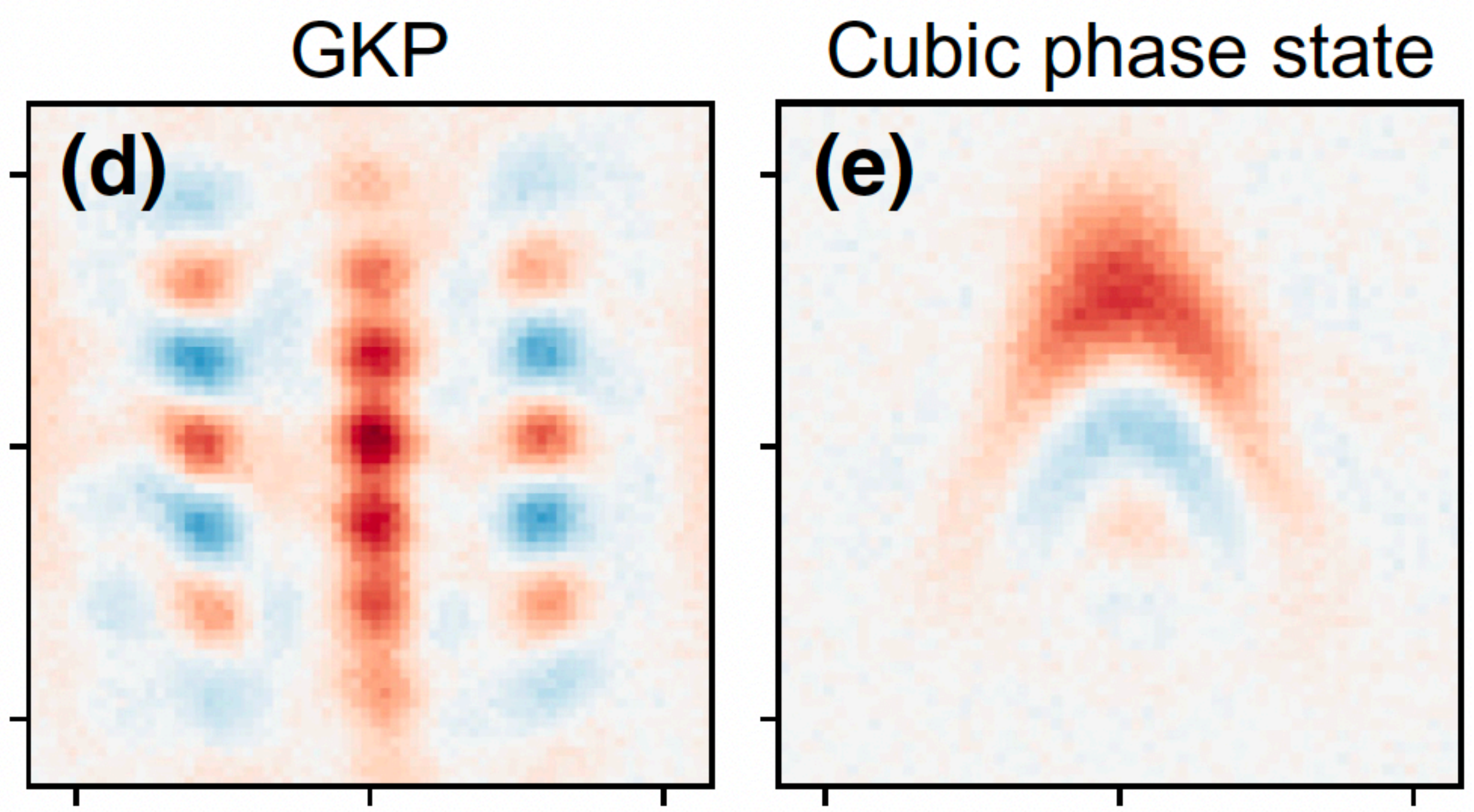
25-qubit QPU





Bosonic quantum states





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- 1,000+ research collaborations globally
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