Radiation Impact on Superconducting Qubits (RISQ 2024)

Report of Contributions

Contribution ID: **1** Type: **not specified**

Superconducting qubit dephasing correlated with radiating events

A major issue currently impeding qubit error-correction is spatially correlated qubit decoherence which is likely caused by cosmic radiation. Superconducting microwave kinetic inductance detectors (MKIDs) are a promising candidate for detection of these events due to their sensitivity to phonon bursts in a substrate. We surrounded a qubit sample with two, three by three arrays of MKIDs which are placed above and below a 6-qubit chip. Detected events on an MKID chip triggered a qubit coherence measurement. We observed a drop in expected qubit T2 time outside the standard deviation for measurements made immediately after a detected event. Further research in such a system will aid in formulating mitigation strategies against errors in large-scale qubit systems.

Prepared by LLNL under Contract DE-AC52-07NA27344.

Primary author: CASTELLI, Alessandro (Lawrence Livermore National Laboratory)

Co-authors: BECK, Kristin; ALEGRIA, Loren; MARTINEZ, Luis; CHAVES, Kevin; O'KELLEY, Sean; DUBOIS, Jonathan; ROSEN, Yaniv

Session Classification: Poster Session

Contribution ID: **2** Type: **not specified**

Controllably irradiating superconducting qubits with gamma rays to characterize quasiparticle poisoning

High-energy radiation, such as gamma rays or muons, poses a threat to the use of superconducting qubit arrays to create a fault-tolerant quantum computer. When such radiation impacts a superconducting qubit chip, many electron-hole pairs and energetic phonons are produced. The electrons and holes can travel some distance and affect the charge environment for the qubits nearby. However, the phonons can travel throughout the chip and have sufficient energy to break Cooper pairs in the device layer, creating quasiparticles and causing errors. Since the phonons can reach all the qubits on the chip, this makes the errors correlated, which challenges standard error correction schemes necessary to implement a fault-tolerant quantum computer. In order to study the effects of radiation, we use a gamma-ray source outside the dilution refrigerator to controllably dose the chip through the cryostat shielding. By using charge-sensitive transmons, we observe both single and correlated events in the charge environment and quasiparticle poisoning in relation to the applied gamma-ray dose. We look at two types of chips: a control chip and one with copper on the back side for phonon downconversion leading to reduced quasiparticle poisoning. With this method, we show that we can characterize quasiparticle poisoning in superconducting qubit chips by controlling the surrounding radiation environment with a gamma-ray source.

Primary authors: LARSON, Clayton (Syracuse University); DODGE, Kenneth; OKUBO, Kiichi; YELTON, Eric; PLOURDE, B.L.T.

Session Classification: Poster Session

Contribution ID: **3** Type: **not specified**

Optimal Experimental Design for Quantum Circuits: A case study for the mitigation of quasiparticle poisoning

Superconducting circuits are the most widely used system for quantum computing, and many of the key accomplishments in this field have been performed using superconducting-based quantum processors. The improvement of device performance through the mitigation and control of qubit errors is currently a critical step for executing complex quantum algorithms. However, the experimental routines used to test error mitigation strategies are often pointwise, time-consuming, and costly. Instead of an unguided research strategy, Optimal Experimental Design (OED) is a methodological approach used to maximize the information gained from a limited number of iteratively designed, computationally optimized experiments. We are developing such a methodology for the design of quantum circuits. To demonstrate the benefits of our OED methodology, we apply it to the problem of quasiparticle poisoning (QP) in superconducting quantum devices, wherein environmental high-energy radiation creates qubit errors. Our OED methodology uses key advances in the computational simulation of QP physics and high-performance-computing optimization techniques to design quantum chips that are more resilient against QP-induced errors. Ongoing work and results will be presented.

Primary author: BAITY, Paul (Brookhaven National Laboratory)

Co-authors: HOISIE, Adolfy (Brookhaven National Laboratory); ISENBERG, Natalie (Brookhaven National Laboratory); LOVE, Peter (Brookhaven National Laboratory); PARK, Gilchan (Brookhaven National Laboratory); REYES, Kristofer (Brookhaven National Laboratory); URBAN, Nathan (Brookhaven National Laboratory); WEEDEN, Spencer (University of Wisconsin-Madison); YELTON, Eric (Syracuse University); YOON, Byung-Jun (Brookhaven National Laboratory)

Session Classification: Poster Session

Contribution ID: **4** Type: **not specified**

Investigation of coherence of niobium-based resonators enabled by a fast-sealing microwave cavity

We present our recent work exploring the coherence of niobium-based superconducting devices, with a focus on two aspects. The first aspect is the role of the niobium and substrate surfaces. We use an approach for sample packaging where devices can be quickly isolated in vacuum after metal oxide removal, using a special purpose sealable microwave cavity. The second aspect is the role of film growth and design in quality factors of Nb planar resonators.
An important element of this work is the use of a 3D cavity that can be sealed and evacuated on the order of a few minutes. This technique has the potential to significantly reduce microwave loss by limiting the growth of metal oxides, compared to the common packaging approaches used in the field that expose the device to air for uncontrolled periods of time. The microwave properties of the hermetically sealed cavity were modelled using electromagnetic simulation software and validated through reflection measurements.
We will present the design of several types of structures, including lumped and distributed resonators, used to probe various contributions to loss, including surface and interface loss and quasi-particle losses. We will discuss our recent results on the fabrication and characterization of resonators.

Primary authors: ZHANG, Chi (University of Waterlooc); GERMOND, Richard (University of Waterloo); JANZEN, Noah (University of Waterloo); VALENTE-FELICIANO, Anne-Marie (JLab); BAL, Mustafa; LUPASCU, Adrian (University of Waterloo)

Session Classification: Poster Session

Contribution ID: **5** Type: **not specified**

Low Tc Hafnium Kinetic Inductance Device for Dark Matter Search

Closely related but contrary to Qubits, dark matter detectors are built to be ultra-sensitive to phonons created from impacts in the substrate. TESs have been successfully implemented as phonon sensors on gram-scale detectors. Kinetic inductance devices (KIDs) are naturally suitable for multiplexing readout, which can scale detectors to kilogram scale.
At LBL we focus on low Tc Hafnium KIDs R&D for phonon sensing. 250mK Tc resonators with internal quality factors exceeding 10^5 have been demonstrated. Low Tc not only yields more quasiparticles per unit energy, but also enables quasiparticle trapping from aluminum phonon absorbers. This technique will lead to sub-eV energy threshold kilogram scale dark matter detectors.

Primary authors: SUZUKI, Aritoki (Lawrence Berkeley National Laboratory); LI, Xinran (Lawrence Berkeley national laboratory); GARCIA-SCIVERES, Maurice (LBNL)

Session Classification: Poster Session

Contribution ID: **6** Type: **not specified**

Quasiparticle Posioning, the Low Energy Excess and Stress Relaxation

Both superconducting qubits and low threshold calorimeters see unexpected bursts of energy in their superconductors which decrease in rate after cooldown, often called the "Low Energy Excess" (LEE) in calorimeters and associated with the "Quasiparticle Poisoning" problem in superconducting qubits. I will discuss the evidence linking these two phenomona, and show that the relaxation of glue on the surface of calorimeters or superconducting qubits may be responsable for some of these observations. The relaxation of thermally induced stress in metal films is an excellent candiate for the remainder of these events.

Primary author: ROMANI, Roger (UC Berkeley)

Session Classification: Poster Session

Contribution ID: **7** Type: **not specified**

Quantum Opportunities at the Sanford Underground Research Facility

The Sanford Underground Research Facility (SURF) has been operating for 17 years as an international facility dedicated to advancing compelling multidisciplinary underground scientific research in rare-process physics, as well as offering research opportunities in other disciplines. SURF laboratory facilities include a Surface Campus as well as access to different elevations down to the 4850-foot level (1490 m, 4300 m.w.e.). In addition, the initial phase of construction is underway for new large caverns (nominally 100m L x 20m W x 24m H) on the 4850L (1485 m, 4100 m.w.e.) on the timeframe of next-generation dark matter and neutrino experiments (~2030).

As some experiment activities are completing over the next 1-4 years, a call has been issued for letters of interest in underground space. SURF offers world-class service, including an ultra-low background environment, low-background assay capabilities, and electroformed copper is produced at the facility. SURF is eager to explore opportunities for our facility to serve the needs of the QIS community.

Primary author: HEISE, Jaret (Sanford Underground Research Facility)

Session Classification: Poster Session

Contribution ID: **8** Type: **not specified**

eV-scale Modelling of Low-Energy Backgrounds in Superconducting Tunnel Junctions utilizing GEANT4 and G4CMP

The BeEST experiment searches for physics beyond the standard model (BSM) in the neutrino sector by utilizing the electron capture (EC) decay of 7Be. The 7Be is embedded in superconducting tunnel junction (STJ) sensors such that the low-energy (eV-scale) radiation is detected with high energy resolution and efficiency. Modelling of low-energy backgrounds is crucial to understanding potential beyond standard model (BSM) physics, including low-energy phonon and quasiparticle generation within the superconductors. On this poster, current modelling of these features and corresponding challenges for the BeEST experiment are discussed with aims towards gaining feedback from the community.
The BeEST experiment is funded in part by the Gordon and Betty Moore Foundation (10.37807/GBMF11571), the DOE-SC Office of Nuclear Physics under Award Numbers DE-SC0021245 and DE-FG02-93ER40789, and the LLNL Laboratory Directed Research and Development program through Grants No. 19-FS-027 and No. 20-LW-006. TRIUMF receives federal funding via a contribution agreement with the National Research Council of Canada. The theoretical work was performed as part of the European Metrology Programme for Innovation and Research (EMPIR) Projects No. 17FUN02 MetroMMC and No. 20FUN09 PrimA-LTD. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. DE-AC52- 07NA27344.

Primary author: STONE-WHITEHEAD, Caitlyn (Colorado School of Mines)

Session Classification: Poster Session

Contribution ID: **9** Type: **not specified**

Superconducting Qubits as Quantum Sensors for the Detection of Ionizing Radiation

We present measurements directed toward utilizing a superconducting qubit, not for quantum information processing, but as a quantum sensor for the detection of ionizing radiation. Whereas ionizing radiation presents a potentially serious problem for quantum error correction due to spatially and temporally correlated errors, it represents an opportunity for quantum sensing. A parameter characterizing superconducting qubits is the ratio (EJ/EC) where EJ is the Josephson energy and EC is the charging energy. We report on measurements of transmon qubits with 20 ⊠ (EJ/EC) ⊠ 60 directed toward quantum sensing for the detection of ionizing radiation. Our experiments are designed to measure multiple values for (EJ/EC) on a single die and therefore within a single cooldown. Our experimental design enables an ionizing radiation source at room temperature to be detected by our quantum sensor at low temperature.
This work was performed in part at the Center for Integrated Nanotechnologies, a U.S. DOE Office of Basic Energy Sciences user facility. This work was supported by the Laboratory Directed Research and Development program at Sandia National Laboratories, a multimission laboratory managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

Primary author: FREEMAN, Matthew (Sandia National Laboratories)

Co-authors: SKINNER RAMOS, Sueli Del Carmen (Sandia National Laboratories); LEWIS, Rupert (Sandia National Laboratories); CARR, Stephen (Sandia National Laboratories)

Session Classification: Poster Session

Contribution ID: **10** Type: **not specified**

Creating Correlated Errors on Transmon Qubits Using an Electron Linear Accelerator

Superconducting transmon qubits are known to be susceptible to errors due to ionizing radiation from ambient radioactive decay and cosmic ray sources (muons). Here, we use a ~22 MeV electron linear accelerator (linac) as an on-demand high-energy particle source to study deleterious effects on a multi-qubit transmon system. The linac provides a pulsed, microsecond burst of radiation that can be redirected at our dilution refrigerator to cause qubit errors. We show that the radiation-induced error dynamics of individual qubits, and the system as a whole, can be easily and quickly extracted due to the on-demand nature of our radiation source and rapid few-microsecond qubit measurement cycle. We present differences in error dynamics due to qubit design and state preparation. We also outline how our experimental configuration should accurately mimic the energy deposition from a typical cosmic-ray muon. This testbed provides a useful tool for the investigation of novel qubit design and packaging techniques for the mitigation of radiation-induced errors.

Primary authors: Dr MCJUNKIN, Thomas (JHU Applied Physics Laboratory); Dr HUNT, Alan W (JHU Applied Physics Laboratory); Dr HAARD, Thomas M (JHU Applied Physics Laboratory); Dr JONES-ALBERTY, Yenuel (JHU Applied Physics Laboratory); Mr SPEAR, Matthew K (JHU Applied Physics Laboratory); Dr SCHULTZ, Kevin M (JHU Applied Physics Laboratory)

Session Classification: Poster Session

Contribution ID: **11** Type: **not specified**

Spectroscopic measurements and models of energy deposition in the substrate of quantum circuits by natural ionizing radiation

Naturally occurring background radiation is a potential source of correlated decoherence events in superconducting qubits that will challenge error-correction schemes. To characterize the radiation environment in an unshielded laboratory, we performed broadband, spectroscopic measurements of background events in silicon substrates located inside a millikelvin refrigerator, an environment representative of superconducting qubit systems. We measured the background spectra in silicon substrates of two thicknesses, 500 μm and 1500 μm, and obtained the average event rate and the integrated power deposition. In a 25mm^2 area and the 500 μm substrate, these values are 0.023 events per second and 4.9 keV s^−1, respectively, counting events that deposit at least 40 keV. We find that the spectrum of background events is nearly featureless, and its intensity decreases by a factor of 40 000 between 100 keV and 3 MeV for silicon substrates 500 μm thick. We find the cryogenic measurements to be in good agreement with predictions based on simple measurements of the terrestrial gamma-ray flux outside the refrigerator, published models of cosmic-ray fluxes, a crude model of the cryostat, and radiation-transport simulations. No free parameters are required to predict the background spectra in the silicon substrates. The good agreement between measurements and predictions allows confident assessment of the relative contributions of terrestrial and cosmic background sources and their dependence on substrate thickness. Our spectroscopic measurements are performed with superconducting microresonators located on micromachined silicon islands that define the interaction volume with background radiation. The resonators transduce deposited energy to a readily detectable electrical signal. Microresonator readout closely resembles dispersive superconducting qubit readout, so similar devices—with or without micromachined islands—are suitable for integration with superconducting quantum circuits as detectors for background events. We find in our specific laboratory conditions that gamma-ray emissions from radioisotopes are responsible for the majority of events depositing E <1.5 MeV, while nucleons among the cosmic-ray secondary particles cause most events that deposit more energy. We discuss lessons learned from the construction of an accurate model of background radiation. We also discuss implications for the efficacy of several strategies to reduce the impact of background radiation on quantum circuits. Finally, we discuss logical follow-on work.

See https://arxiv.org/html/2404.10866v1.

Primary authors: ULLOM, Joel (NIST/University of Colorado); FOWLER, Joseph (NIST and University of Colorado); SZYPRYT, Paul (NIST and University of Colorado); BUNKER, Raymond (Pacific Northwest National Laboratory); EDWARDS, Ellen (Pacific Northwest National Laboratory); FOGARTY FLORANG, Ian (NIST and University of Colorado); GAO, Jiansong (NIST and University of Colorado); GIACHERO, Andrea (NIST, University of Colorado, and University of Milano-Bicocca); HOOGERHEIDE, Shannon (NIST); LOER, Ben (Pacific Northwest National Laboratory); MUMM, H. Pieter (NIST); NAKAMURA, Nathan (NIST and University of Colorado); O'NEIL, Galen C. (NIST); ORRELL, John L. (Pacific Northwest National Laboratory); SCOTT, Elizabeth M. (Centre College); STEVENS, Jason (NIST and University of Colorado); SWETZ, Daniel S. (NIST); VANDEVENDER, Brent A. (Pacific Northwest National Laboratory); VISSERS, Michael (NIST)

Session Classification: Poster Session

Contribution ID: **12** Type: **not specified**

Development of qubit-based light dark matter detector on sapphire substrate

One of the challenges in exploring target materials for dark matter searches is the detection of sub-eV energy excitations from light dark matter interaction with a target material. Dark matter interaction can excite sub-eV optical phonon modes in polar materials like sapphire. Furthermore, the anisotropy of sapphire crystal could provide a signature of daily modulation of the dark matter scattering rate, making it a promising target material. We plan to utilize superconducting qubits on a sapphire substrate to detect the scattering events by taking advantage of the excitation of phonons, which scatter and further down-convert to lower-energy phonons. A good fraction of these phonons are expected to reach the qubit superconductor on the substrate and break Cooper pairs. Such a process can cause qubit decoherence, which can be measured using standard qubit readout protocol. This poster describes our ongoing development of a prototype detector.

Primary author: ANYANG, Kester (Illinois Institute of Technology)

Session Classification: Poster Session

Contribution ID: **13** Type: **not specified**

Welcome and goals of the workshop

Thursday, 30 May 2024 09:00 (15 minutes)

Primary authors: GRASSELLINO, Anna (Fermilab); CRIPE, Jonathan (LPS); HUMBLE, Travis (Oak Ridge National Laboratory)

Presenters: GRASSELLINO, Anna (Fermilab); CRIPE, Jonathan (LPS); HUMBLE, Travis (Oak Ridge National Laboratory)

Session Classification: Day 1

Contribution ID: **14** Type: **not specified**

Plenary Overview

Thursday, 30 May 2024 09:15 (1 hour)

Primary author: MCEWEN, Matthew

Presenter: MCEWEN, Matthew

Session Classification: Day 1

Contribution ID: **15** Type: **not specified**

Summary of QSC Efforts

Thursday, 30 May 2024 10:30 (30 minutes)

Primary author: BAXTER, Daniel

Presenter: BAXTER, Daniel

Session Classification: Day 1

Contribution ID: **16** Type: **not specified**

Summary of SQMS Efforts

Thursday, 30 May 2024 11:00 (30 minutes)

Primary author: ROY, Tanay (Fermilab)

Presenter: ROY, Tanay (Fermilab)

Session Classification: Day 1

Contribution ID: **17** Type: **not specified**

Summary of C2QA Efforts

Thursday, 30 May 2024 11:30 (15 minutes)

Primary author: VANDEVENDER, Brent A. (Pacific Northwest National Laboratory)

Presenter: VANDEVENDER, Brent A. (Pacific Northwest National Laboratory)

Session Classification: Day 1

Contribution ID: **18** Type: **not specified**

Discussion

Thursday, 30 May 2024 11:45 (15 minutes)

Session Classification: Day 1

Contribution ID: **19** Type: **not specified**

Panel

Thursday, 30 May 2024 15:30 (1h 30m)

Presenters: CLELAND, Andrew; MARTINIS, John; FAORO , Lara; CARDANI, Laura; THORBECK, Ted

Session Classification: Day 1

Contribution ID: **20** Type: **not specified**

Muon tagging using Kinetic Inductance Detectors

Thursday, 30 May 2024 13:00 (15 minutes)

Ionizing radiation, particularly environmental radioactivity and cosmic-ray muons, pose significant challenges to the coherence and reliability of superconducting quantum processors. In this talk, I will introduce a novel approach to mitigate the detrimental effects of atmospheric muons on arrays of superconducting qubits. Our strategy involves equipping a superconducting quantum processor with an active muon veto system designed to tag and veto operations following a muon interaction within the chip. I will outline the concept, design, and technology behind the muon veto detector, with a focus on achieving high detection efficiency and negligible dead-time. Leveraging insights from Particle Physics experiments and the INFN CALDER project, we propose a cryogenic muon veto based on Kinetic Inductance Detectors (KIDs) technology, tightly integrated with the superconducting quantum chip. Results from Monte Carlo simulations and a preliminary design of the muon veto will be presented. By demonstrating the effectiveness of this strategy, we aim to significantly reduce correlated errors, enhancing both coherence and frequency stability of superconducting qubits. We plan to test our prototype using a high-performing quantum chip provided by the Superconducting Quantum Materials and Systems (SQMS) Center, with the objective of validating its performance and applicability in practical quantum computing scenarios.

Primary author: MARIANI, Ambra (INFN - Sezione di Roma)

Presenter: MARIANI, Ambra (INFN - Sezione di Roma)

Session Classification: Day 1

Contribution ID: **21** Type: **not specified**

External muon tagging

Thursday, 30 May 2024 13:15 (15 minutes)

Primary author: HARRINGTON, Patrick

Presenter: HARRINGTON, Patrick

Session Classification: Day 1

Contribution ID: **22** Type: **not specified**

Phonon Trapping

Thursday, 30 May 2024 13:30 (15 minutes)

Primary author: PLOURDE, Britton

Presenter: PLOURDE, Britton

Session Classification: Day 1

Contribution ID: **23** Type: **not specified**

Phonon Funneling (SQUATs)

Thursday, 30 May 2024 13:45 (15 minutes)

Primary author: KURINSKY, Noah (SLAC National Laboratory)

Presenter: KURINSKY, Noah (SLAC National Laboratory)

Session Classification: Day 1

Contribution ID: **24** Type: **not specified**

IR Mitigation

Thursday, 30 May 2024 14:00 (15 minutes)

Primary author: CHANG, Yen-Yung (UC Berkeley)

Presenter: CHANG, Yen-Yung (UC Berkeley)

Session Classification: Day 1

Contribution ID: **25** Type: **not specified**

Theory Perspectives

Thursday, 30 May 2024 14:15 (15 minutes)

Primary author: CATELANI, Gianluigi

Presenter: CATELANI, Gianluigi

Session Classification: Day 1

Contribution ID: **26** Type: **not specified**

G4CMP Workshop Summary

Thursday, 30 May 2024 14:30 (30 minutes)

Session Classification: Day 1

Contribution ID: **27** Type: **not specified**

Discussion

Thursday, 30 May 2024 15:00 (15 minutes)

Session Classification: Day 1

Contribution ID: **28** Type: **not specified**

Quasiparticle poisoning in topological qubits

Friday, 31 May 2024 09:00 (20 minutes)

Primary author: KARZIG, Torsten

Presenter: KARZIG, Torsten

Session Classification: Day 2

Contribution ID: **29** Type: **not specified**

Quantum Dots

Friday, 31 May 2024 09:20 (20 minutes)

Presenter: ERIKSSON, Mark

Session Classification: Day 2

Contribution ID: **30** Type: **not specified**

TBD

Friday, 31 May 2024 09:40 (20 minutes)

Session Classification: Day 2

Contribution ID: **31** Type: **not specified**

Microelectronics

Friday, 31 May 2024 10:00 (20 minutes)

Presenter: FAHIM, Farah (FERMILAB)

Session Classification: Day 2

Contribution ID: **32** Type: **not specified**

Fermilab Underground Facilities (QUIET & NEXUS)

Friday, 31 May 2024 10:30 (15 minutes)

Primary author: FIGUEROA-FELICIANO, Enectali (Northwestern University)

Presenter: FIGUEROA-FELICIANO, Enectali (Northwestern University)

Session Classification: Day 2

Contribution ID: **33** Type: **not specified**

PNNL Underground Facilities

Friday, 31 May 2024 10:45 (15 minutes)

Primary author: LOER, Ben (Pacific Northwest National Laboratory)

Presenter: LOER, Ben (Pacific Northwest National Laboratory)

Session Classification: Day 2

Contribution ID: **34** Type: **not specified**

SNOLAB Underground Facilities

Friday, 31 May 2024 11:00 (15 minutes)

Presenter: KUBIK, Andrew

Session Classification: Day 2

Contribution ID: **35** Type: **not specified**

LNGS Underground Facilities

Friday, 31 May 2024 11:15 (15 minutes)

Presenter: PIRRO , Stefano

Session Classification: Day 2

Contribution ID: **36** Type: **not specified**

IFAE Underground Facilities

Friday, 31 May 2024 11:30 (15 minutes)

Primary author: BERTOLDO, Elia

Presenter: BERTOLDO, Elia

Session Classification: Day 2

Contribution ID: **37** Type: **not specified**

Boulby Underground Facilities

Friday, 31 May 2024 11:45 (15 minutes)

Primary author: KEMP, Ashlea (RHUL)

Presenter: KEMP, Ashlea (RHUL)

Session Classification: Day 2

Contribution ID: **38** Type: **not specified**

An Electron Linear Accelerator for On-Demand Qubit Irradiation

Friday, 31 May 2024 12:30 (15 minutes)

Presenter: MCJUNKIN, Tom

Session Classification: Day 2

Contribution ID: **39** Type: **not specified**

Australia Underground Facilities

Friday, 31 May 2024 12:00 (15 minutes)

Primary author: MCALLISTER, Ben (ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, University of Western Australia)

Presenter: MCALLISTER, Ben (ARC Centre of Excellence for Engineered Quantum Systems, School of Physics, University of Western Australia)

Session Classification: Day 2

Contribution ID: **40** Type: **not specified**

The Colorado Shallow Underground Research Facility at the Edgar Experimental Mine

Friday, 31 May 2024 12:15 (15 minutes)

Presenter: KEBLBECK, Dakota

Session Classification: Day 2

Contribution ID: **41** Type: **not specified**

Disentangling the sources of ionizing radiation in superconducting qubits

Radioactivity was recently discovered as a source of decoherence and correlated errors for the real-world imple- mentation of superconducting quantum processors. In this work, we measure levels of radioactivity present in a typical laboratory environment (from muons, neutrons, and γ -rays emitted by naturally occurring radioactive isotopes) and in the most commonly used materials for the assembly and oper- ation of state-of-the-art superconducting qubits. We present a GEANT-4 based simulation to predict the rate of impacts and the amount of energy released in a qubit chip from each of the mentioned sources. We finally propose mitigation strategies for the operation of next-generation qubits in a radio-pure environment.

Primary authors: Dr ROMANENKO, Alexander (Fermi National Accelerator Laboratory); Dr MARIANI, Ambra (INFN, Sezione di Roma); Dr CRUCIANI, Angelo (INFN, Sezione di Roma); DE DOMINICIS, Francesco (Gran Sasso Science Institute, Istituto Nazionale di Fisica Nucleare); Dr GRASSELLINO, Anna (Fermi National Accelerator Laboratory); Dr KOPAS, Cameron (Rigetti Computing); Dr TOMEI, Claudia (INFN, Sezione di Roma); Dr MCRAE, Corey Rae (National Institute of Standards and Technology, Department of Physics, University of Colorado, Department of Electrical, Computer and Energy Engineering, University of Colorado Boulder); Dr PAPPAS, D. P. (Rigetti Computing); Dr FROLOV, Danii (Fermi National Accelerator Laboratory); Dr VAN ZANTEN, David (Fermi National Accelerator Laboratory); Dr LACHMAN, Ella (Rigetti Computing); Prof. FERRONI, Fernando (INFN, Sezione di Roma and Gran Sasso Science Institute); Dr D'IMPERIO, Giulia (INFN, Sezione di Roma); Dr COLANTONI, Ivan (INFN, Sezione di Roma and Consiglio Nazionale delle Ricerche, Istituto di Nanotecnologia); Mrs WITHROW, J. D. (Physics Department, University of Florida); Dr MUTUS, Josh (Rigetti Computing); Dr CARDANI, Laura (INFN, Sezione di Roma); Dr PAGNANINI, Lorenzo (Gran Sasso Science Institute, INFN, Laboratori Nazionali del Gran Sasso and Department of Physics and Engineering Physics Astronomy, Queen's University Kingston); Prof. GIRONI, Luca (Dipartimento di Fisica, Università di Milano-Bicocca and INFN, Sezione di Milano-Bicocca); Prof. VIGNATI, Marco (INFN, Sezione di Roma and Dipartimento di Fisica, Sapienza Università di Roma); Dr NASTASI, Massimiliano (Dipartimento di Fisica, Università di Milano-Bicocca, INFN, Sezione di Milano-Bicocca); Dr JUNKER, Matthias (INFN, Laboratori Nazionali del Gran Sasso); Dr LAUBENSTEIN, Matthias (INFN, Laboratori Nazionali del Gran Sasso); Dr SISTI, Monica (INFN, Sezione di Milano-Bicocca); Dr ZHELEV, N. Z. (Center for Applied Physics and Superconducting Technologies, Northwestern University); Dr CASALI, Nicola (INFN, Sezione di Roma); Dr PILIPENKO, Roman (Fermi National Accelerator Laboratory); Dr PIRRO, Stefano (INFN, Laboratori Nazionali del Gran Sasso); Dr PETTINACCI, Valerio (INFN, Sezione di Roma)

Session Classification: Poster Session

Contribution ID: **42** Type: **not specified**

Applications of Strain Sensing for Superconducting Qubit Devices

Optomechanical strain sensing provides attractive opportunities for studying stress-induced (i.e. non-radiogenic) phonon bursts, which have been demonstrated to limit the coherence times and minimum charge jump rates of superconducting qubits [1,2,3]. We are investigating SiN microring optical resonator strain sensors, developed at Purdue University [4], for applications in QIS and fundamental particle sensing. These sensors can be embedded in the substrate upon which superconducting qubits are patterned, providing a handle to distinguish decoherence events of radiogenic origin from those due to crystal stress, as they are expected to be largely inert to the former. These strain sensors have so far found application in photonics and communications, but provide unique capabilities for studying the stresses present within superconducting films and device substrates in order to improve qubit error-robustness and coherence times. A test platform for these devices has been established at Fermilab to evaluate their cryogenic performance and investigate the feasibility of deploying them alongside superconducting qubits to understand the impact of stress release on qubit operation.

[1] Mannila et al. A superconductor free of quasiparticles for seconds. Nat. Phys. 18, 145–148 (2022). https://doi.org/10.1038/s41567-021-01433-7
[2] Cardani et al. Reducing the impact of radioactivity on quantum circuits in a deep-underground facility. Nat Commun 12, 2733 (2021). https://doi.org/10.1038/s41467-021-23032-z
[3] Bratrud et al. First Measurement of Correlated Charge Bursts in Superconducting Qubits at an Underground Facility. In preparation (2024).
[4] Tian et al. Hybrid integrated photonics using bulk acoustic resonators. Nat Commun 11, 3073 (2020). https://doi.org/10.1038/s41467-020-16812-6

Primary author: TEMPLES, Dylan (Fermilab)

Session Classification: Poster Session

Contribution ID: **43** Type: **not specified**

Ta Based Damascene Resonators

The latest performance improvement in superconducting transmon qubits is associated to changes in materials and surface engineering. These approaches yield coherence time up to 0.5 milliseconds for Ta based devices, with Nb-based qubits following closely. This improvement is attributed to the oxidation state of Ta vs Nb, which effect the Two-Level-System (TLS) noise in associated devices. As such, studies focused on oxidation and surface treatment/engineering are ongoing to verify and further improve device performance by exploring losses in superconducting resonators. PNNL is collaborating with NY CREATES/SUNY Poly and BNL to study the effects of fabricating damascene Ta resonators in high-resistivity silicon substrates. We have recently characterized these resonators demonstrating a current best Q on the order of 10^5 at low power. We will discuss these results and the prospect for further improvements.

Primary author: Dr PONCE, Francisco (Pacific Northwest National Laboratory)

Co-authors: Dr BHATIA, Ekta (NY CREATES/University of Albany (SUNY)); Dr ZHOU, Chenyu (Brookhaven National Laboratory); Dr LIU, Mingzhao (Brookhaven National Laboratory); Dr NANAYAKKARA, Tharanga (Brookhaven National Laboratory); Dr PAPA RAO, Satyovolu (NY CREATES/University of Albany (SUNY)); Dr WARNER, Marvin (Pacific Northwest National Laboratory); Dr REBAR, Drew (Pacific Northwest National Laboratory); Mr MACY, Juan (Pacific Northwest National Laboratory); Dr VANDEVENDER, Brent (Pacific Northwest National Laboratory)

Session Classification: Poster Session

Contribution ID: **44** Type: **not specified**

First Measurement of Correlated Charge Noise in Superconducting Qubits at an Underground Facility

Recent work indicates that non-equilibrium quasiparticles can contribute to decoherence effects in superconducting qubits. Ionizing radiation, for example, has been shown to create errors in qubit arrays that are correlated in both space and time. For quantum computing, such correlated errors create problems for standard error-correcting codes. For quantum sensing, these same phenomena can represent a possible measurement channel (sensing particle interactions in the qubit substrate) or a possible background (increasing quasiparticle-induced decoherence). We present results from measurements of an array of weakly charge-sensitive superconducting qubits exposed to a range of radiation fluxes. These experiments were done at the NEXUS low-background test stand 100 meters (225 m.w.e.) underground at Fermilab's MINOS experimental area, allowing for greater control over radiation fluxes than is typically available in above-ground lab environments. We discuss correlations between radiation flux and the stability of qubit gate charge, as well as the implications of these observations for future qubit-based dark matter experiments.

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Session Classification: Poster Session

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Simulation Framework for Non-equilibrium Mode-resolved Phonon-mediated Quasiparticle Poisoning in Superconducting Qubits

Superconducting qubits are susceptible to non-equilibrium phonon excitations which incite chip-wide quasiparticle burst events responsible for the energy relaxation and dephasing of the qubit states. In this work, we demonstrate a phonon-mode resolved simulation framework governed by *ab initio* data (force constants, phonon lifetimes, electron-phonon coupling matrix, etc.) to describe phonon-mediated quasiparticle poisoning initiated by the absorption of an impinging gamma photon in the device substrate. The critical steps are electron ionization and thermalization which give the initial excited phonon population, non-equilibrium phonon transport in the millikelvin thermal bath, interfacial phonon transmission across the superconductor-substrate interface, and finally, non-equilibrium phonon-quasiparticle dynamics in the superconductor.

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Incorporating Phonon Kinematics of Novel Materials in G4CMP to Study Qubit Chip Response to Energy Deposits

The Geant4 Condensed Matter Physics (G4CMP) toolkit was designed to simulate the transport of charge and phonons in detectors made of Silicon and Germanium. Through these simulations, the toolkit effectively reproduces phenomena such as heat-pulse propagation times, average charge-carrier drift velocities, and phonon caustics. However, its limitation to Silicon and Germanium restricts its applicability to other fields such as material and quantum science research, as well as the exploration of new materials for Dark Matter detection. To address this, we expand the capabilities of G4CMP to include several novel materials like Sapphire (Al2O3), Gallium Arsenide (GaAs), Lithium Fluoride (LiF). Specifically, we integrate parameters to facilitate the phonon kinematics simulations in G4CMP. We present various phonon caustic patterns for these materials and compare them with experimental phonon caustic images. Additionally, we create a comprehensive simulation framework, utilizing G4CMP, to assess the performance metrics of qubit chips operating in a gate-based "energy relaxation" readout scheme.

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Estimating the Energy Threshold of Qubit-based Detectors in a Relaxation Sensing Scheme

Over the last decade, several low-energy physics searches, including the hunt for particle dark matter, have driven interest in developing increasingly sensitive particle detectors. Superconducting quantum sensors based on Cooper Pairs provide a possible channel for sensing O(meV) energy depositions, and therefore could represent a significant step in developing such low-threshold detectors. In this poster we present a bottom-up estimate of the energy threshold of a superconducting qubit operated in an energy-relaxation sensing scheme. We model the in-substrate phonon response with the G4CMP low-energy physics simulation package and model the evolution of phonon-created quasiparticles and qubit state with a custom package called QDR (Quantum Device Response). Using a novel energy reconstruction technique for qubits operated in this sensing scheme, we estimate an in-qubit energy threshold for near-term devices of approximately 0.4 eV. Moreover, we confirm the validity of this technique by applying it to recently published data in which cosmic rays were observed to pass through a qubit chip.

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