JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

An Electron Linear Accelerator for On-Demand Qubit Irradiation

RISQ 2024

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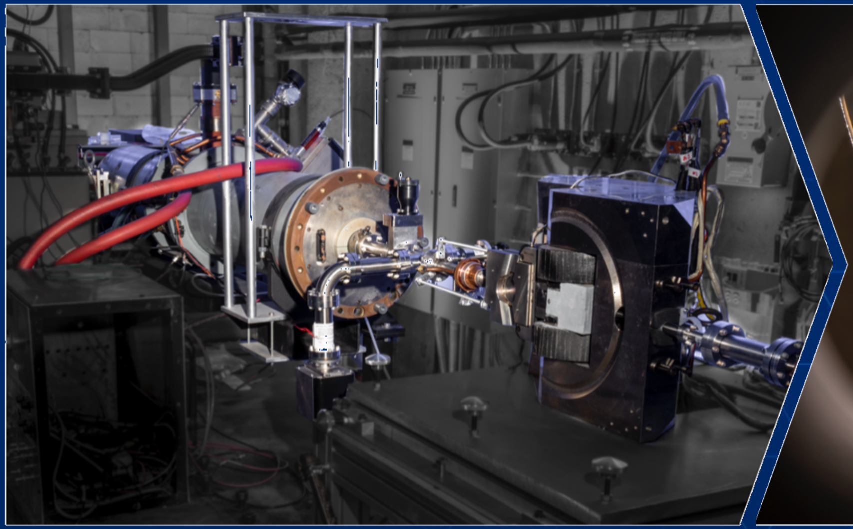

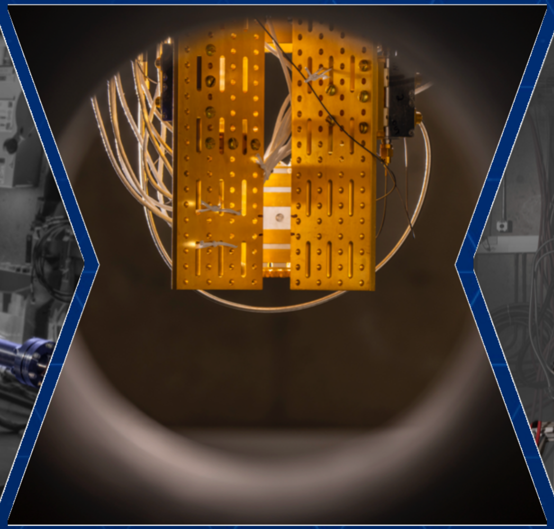

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Motivation: Studying high-energy impacts on qubits requires long data collection times.

- Naturally occurring high-energy impact events on quantum systems are rare (seconds to minutes).
- Radioactive sources can increase the frequency of impacts, but event timing is still stochastic.
- Heralded event tagging using external detectors is only useful for massive particles.

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McEwen, et al., 2024	1.7 hours
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Solution

Use a tunable radiation source that can be triggered for on-demand impact events.

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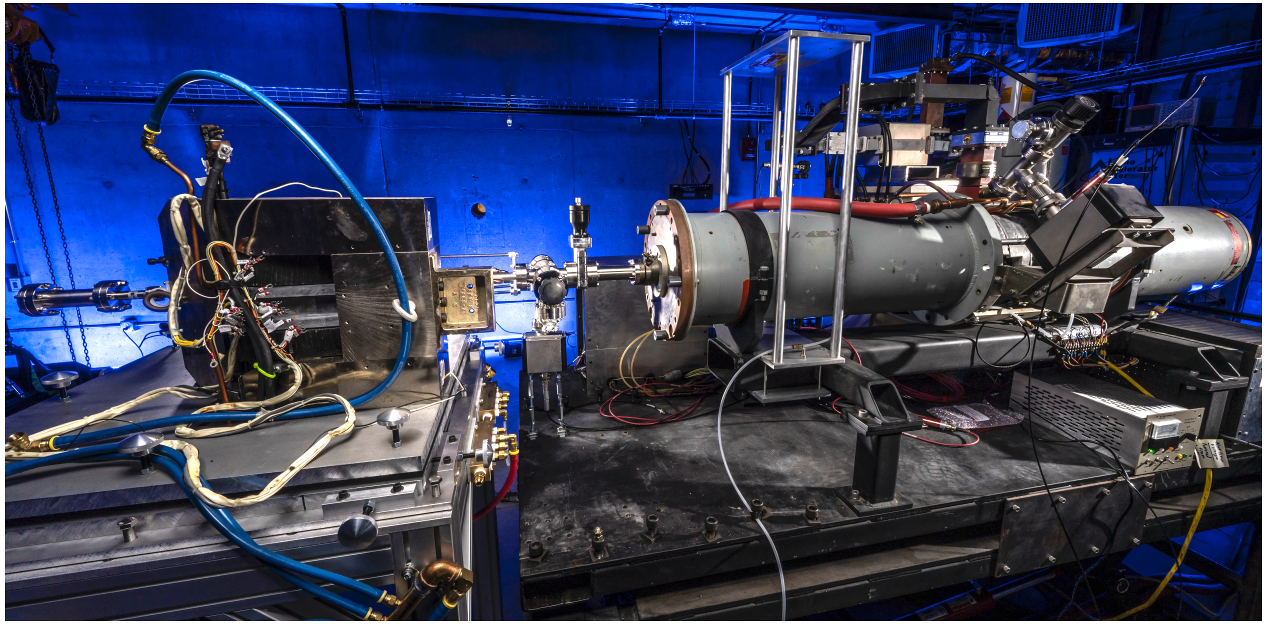
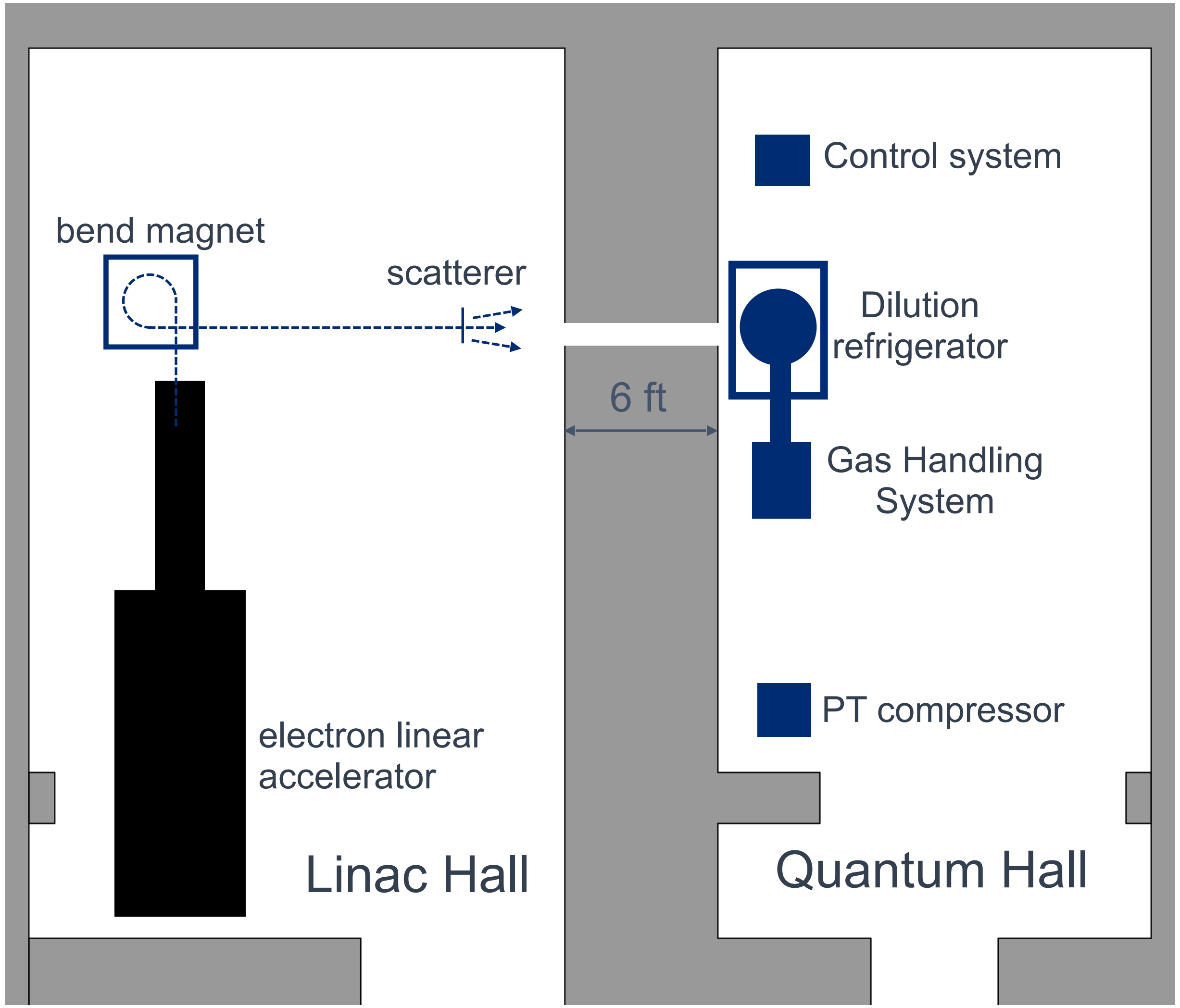
This work	10 minutes

At APL, we have built a qubit measurement facility in the beamline of an electron linear accelerator.

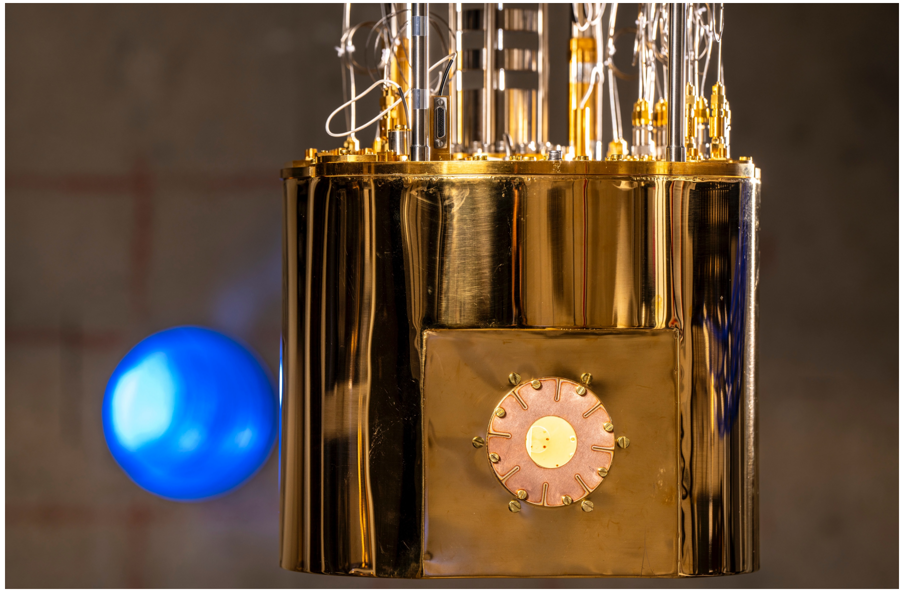
- Linac acts as a pulsed radiation source.
  - Electron energy: 5 - 25 MeV
  - Pulsed system up to 100 Hz
  - Electron pulse width: 20 ns - 4 μs
  - Average current: 0 - 50 μA

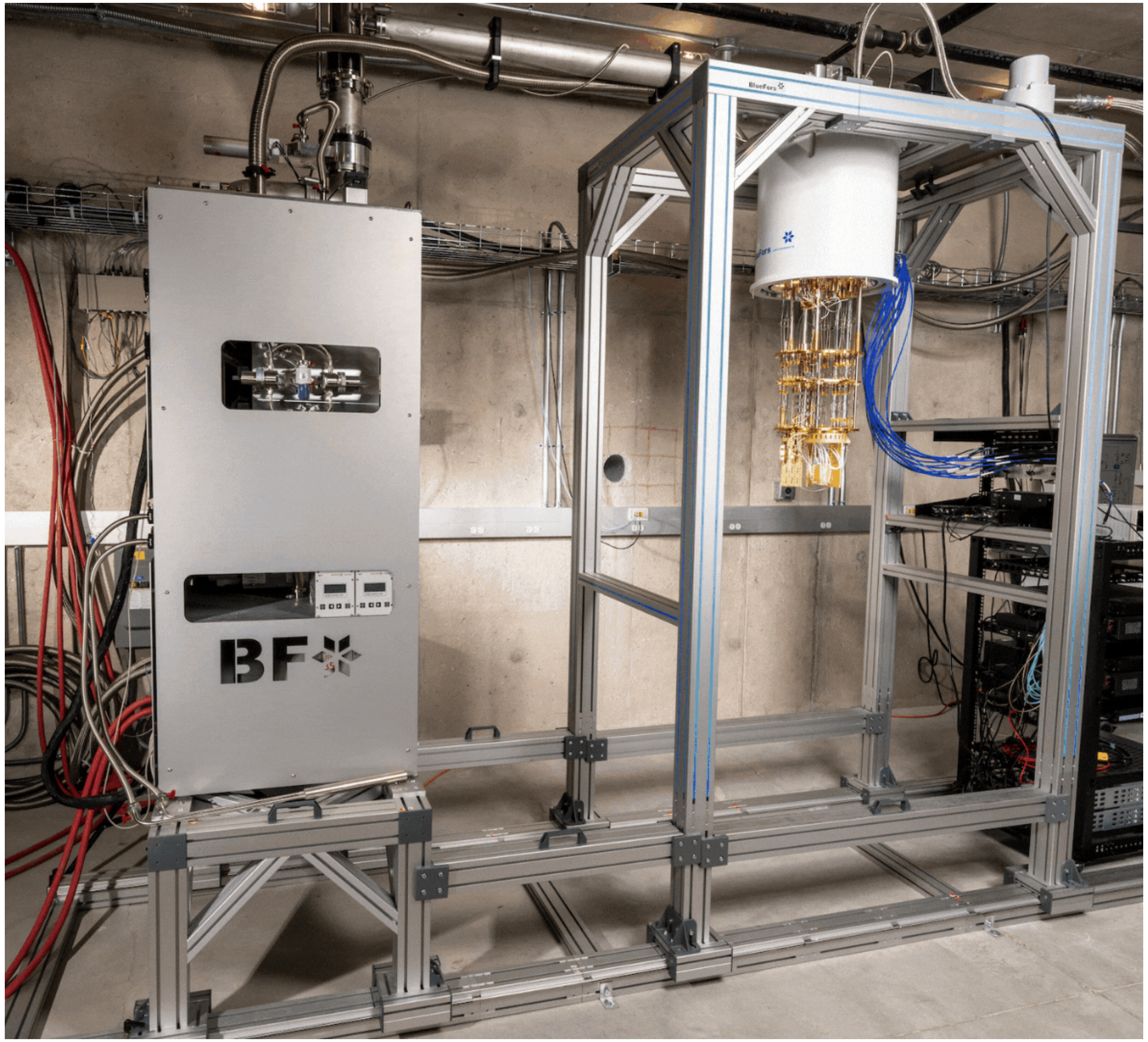




The qubit fridge is modified and mobile.

- Dilution refrigerator is raised to match the beam height of the accelerator and placed on a rolling track for easy removal from the beamline.
- Modified shielding cans have thin (~25 μm) windows to allow maximum energy deposition from primary electrons.





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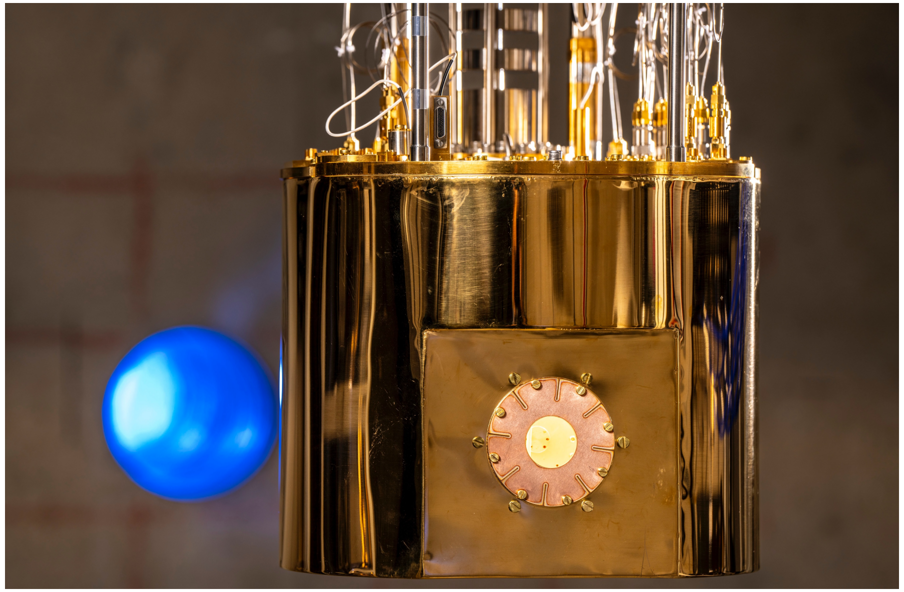
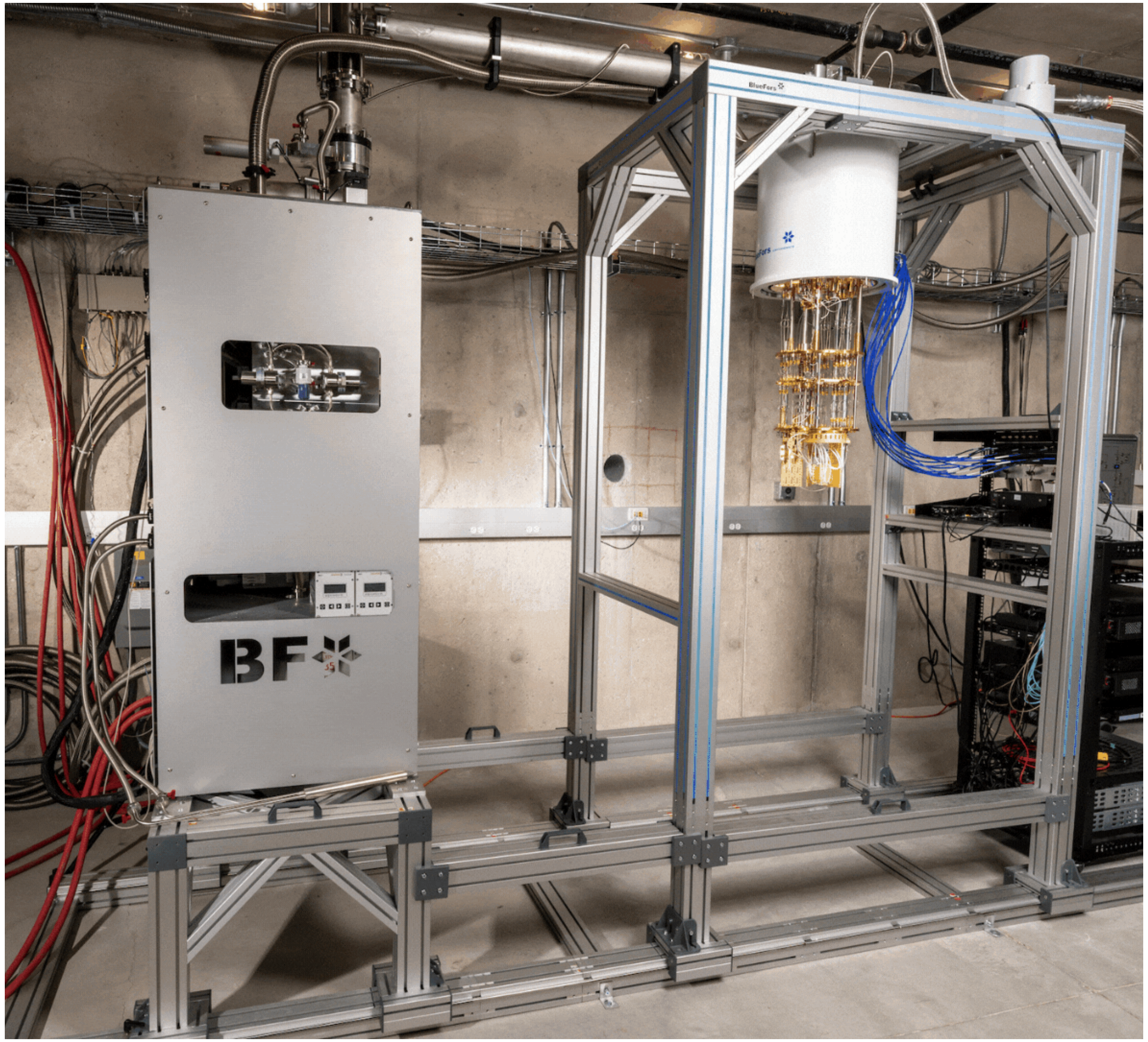
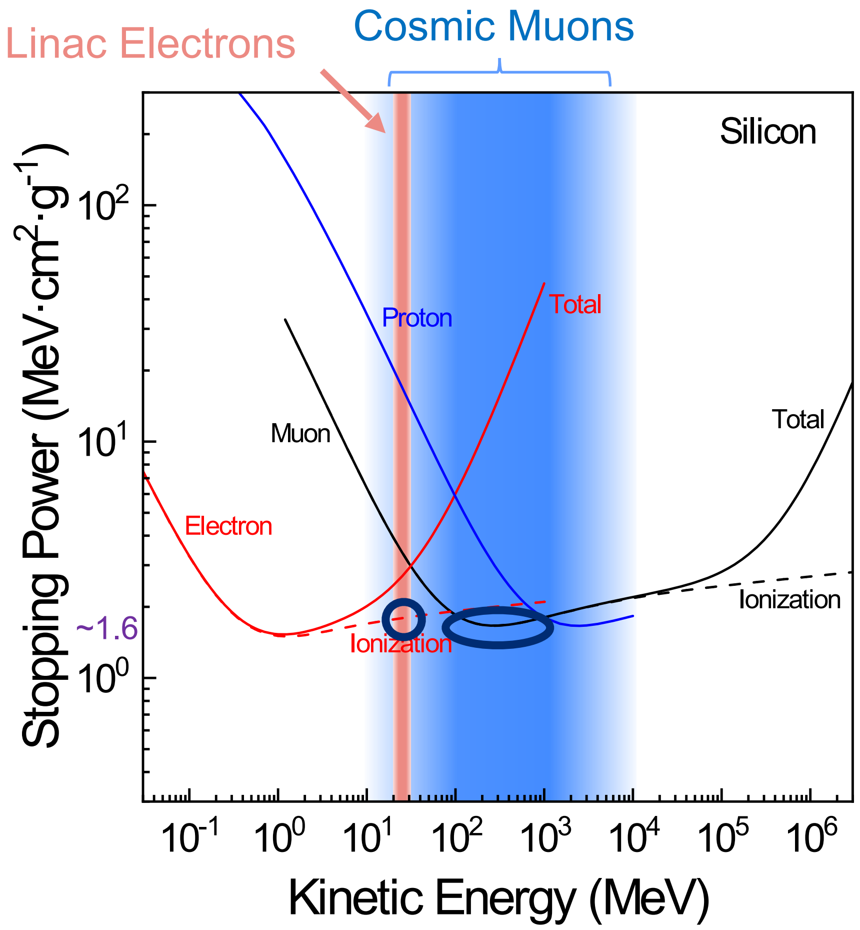
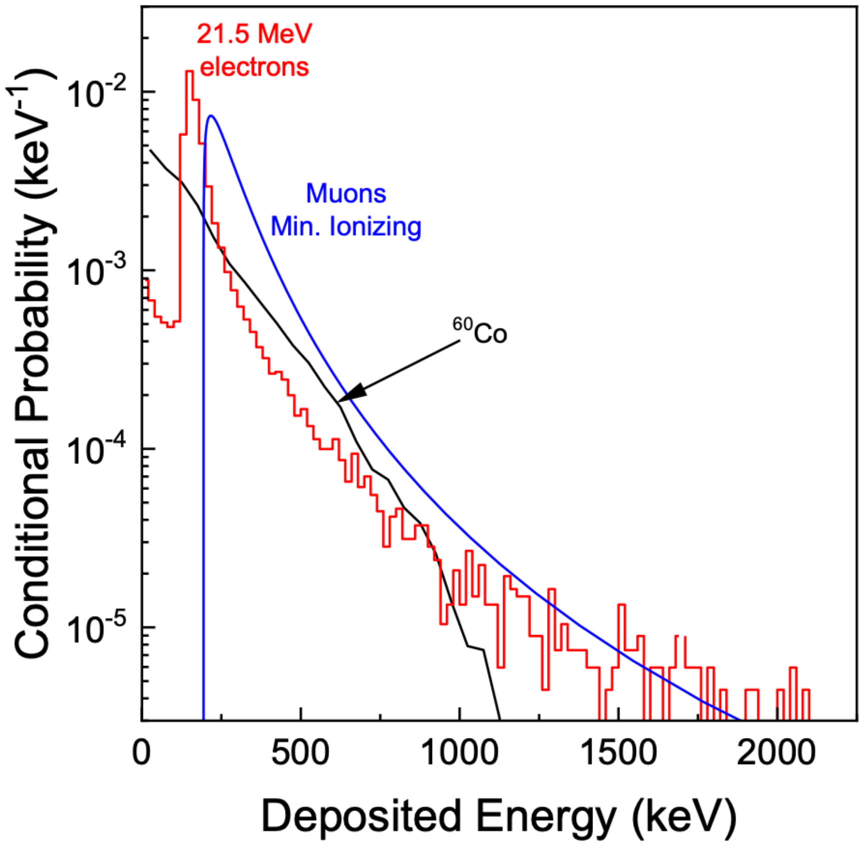




Linac electrons act as a muon surrogate.

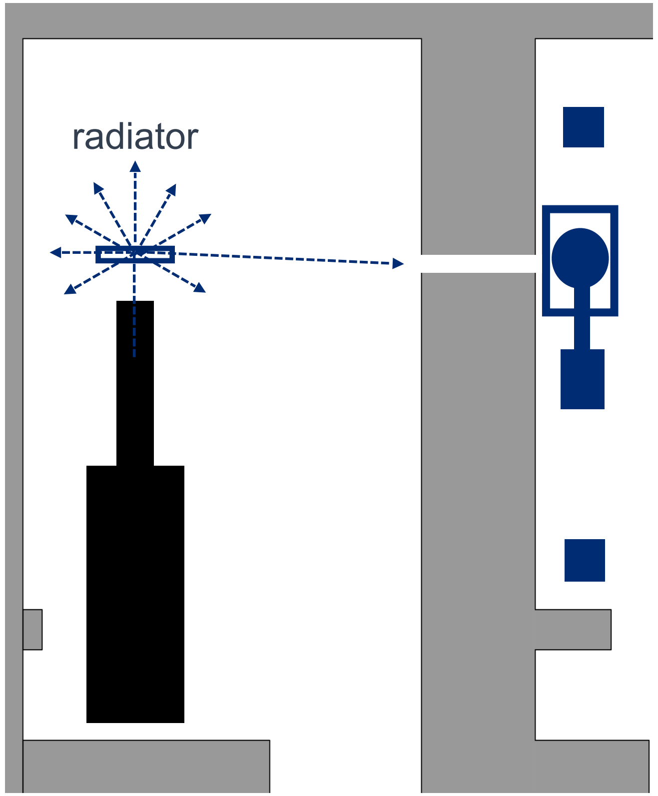


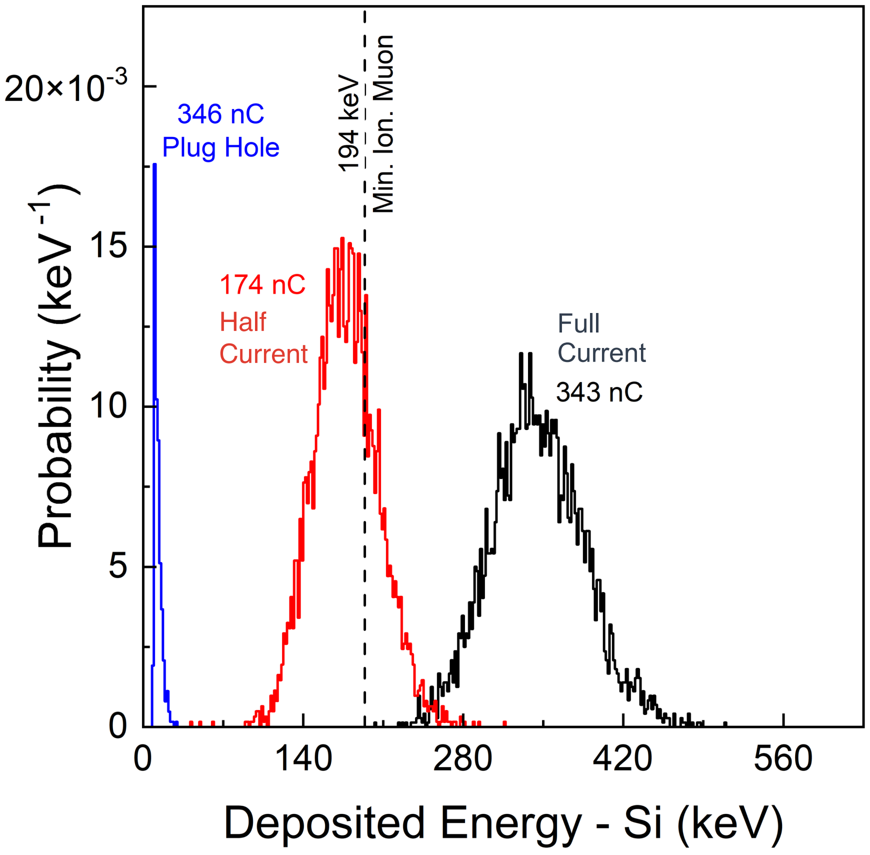


The energy deposited in a silicon chip from a single linac electron is expected to be very similar to a cosmic-ray muon (~200 keV). Larger energy deposition is possible with multiple electrons per shot.

Linac can also be an on-demand gamma source.

- Linac beam can be directed into a radiator to create Bremsstrahlung photons (and electrons).
- A shower of these photons and electrons can impinge on the qubit fridge and cause correlated errors.
- Calculations suggest ~ 1 particle collision with the qubit chip per pulse with the linac at full current.

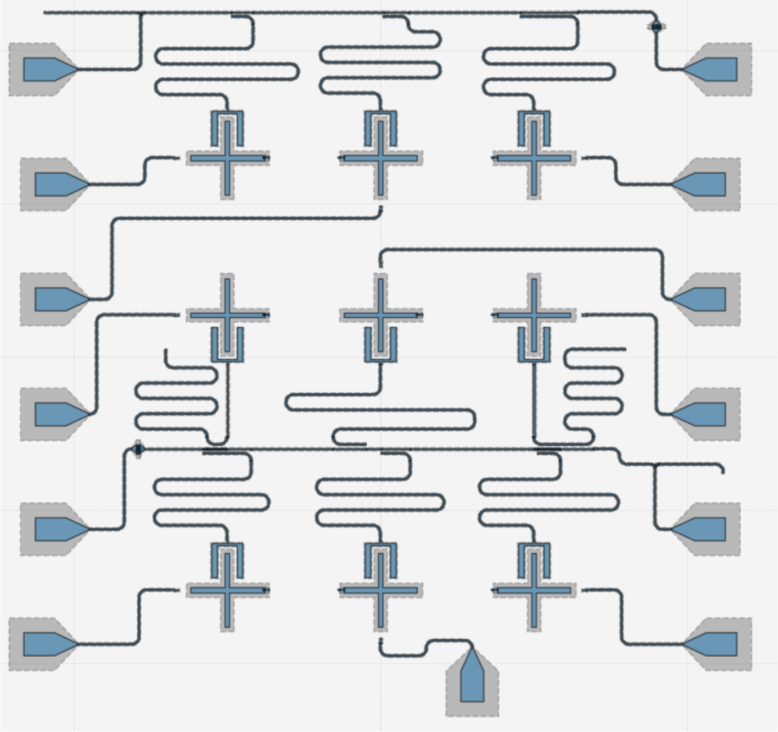


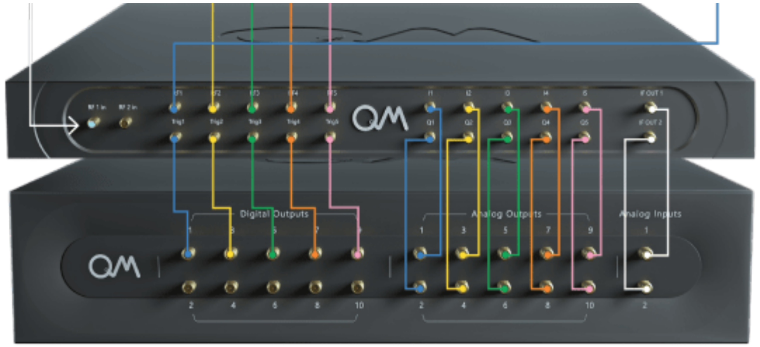


All data presented here uses this scheme of indirect Bremsstrahlung photons from the linac impacting an unmodified fridge.

A multi-qubit system is used for event detection.

- Device Details
  - 9 fixed-frequency transmon qubits, no qubit-qubit coupling
  - SQUILL fabricated, all aluminum on a 5 mm chip
  - T1 across chip is 30 – 90 μs
- Control Details
  - Independent qubit control with Quantum Machines system
  - Fast active reset allows for few-μs timing between shots
  - Measurement scheme is typical T1 error detection (below)
  - Linac trigger is integrated into the qubit data stream





All qubits prepped in excited state

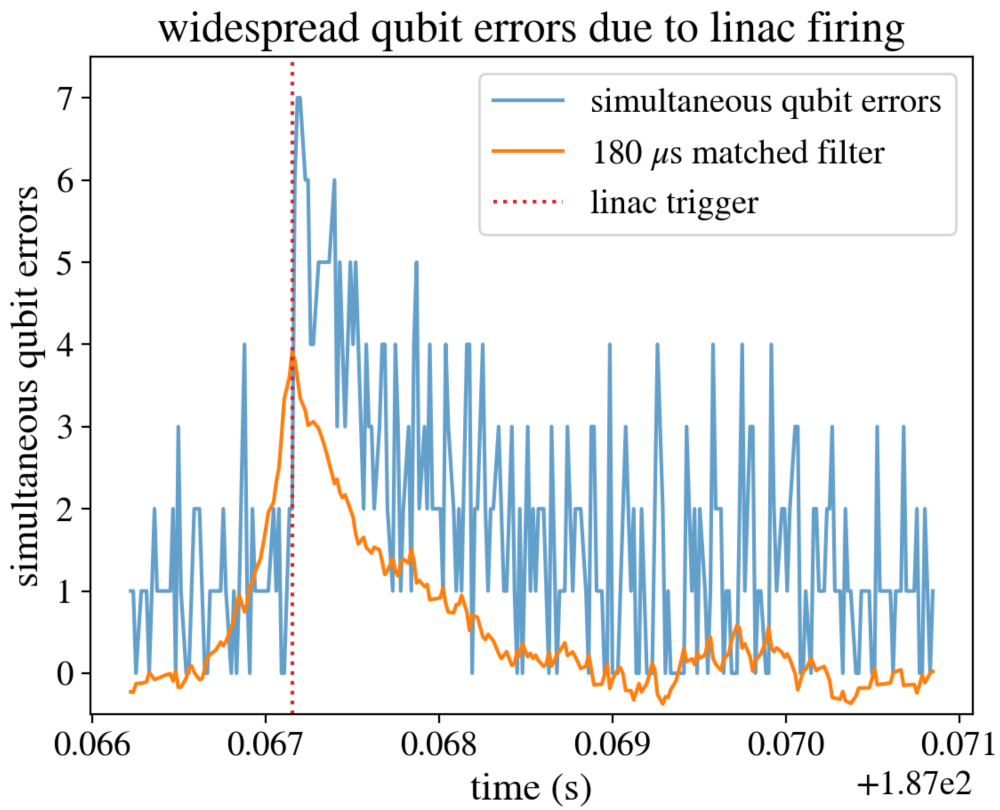
Measure and record "errors" when qubits have relaxed

… prepare — delay — measure …

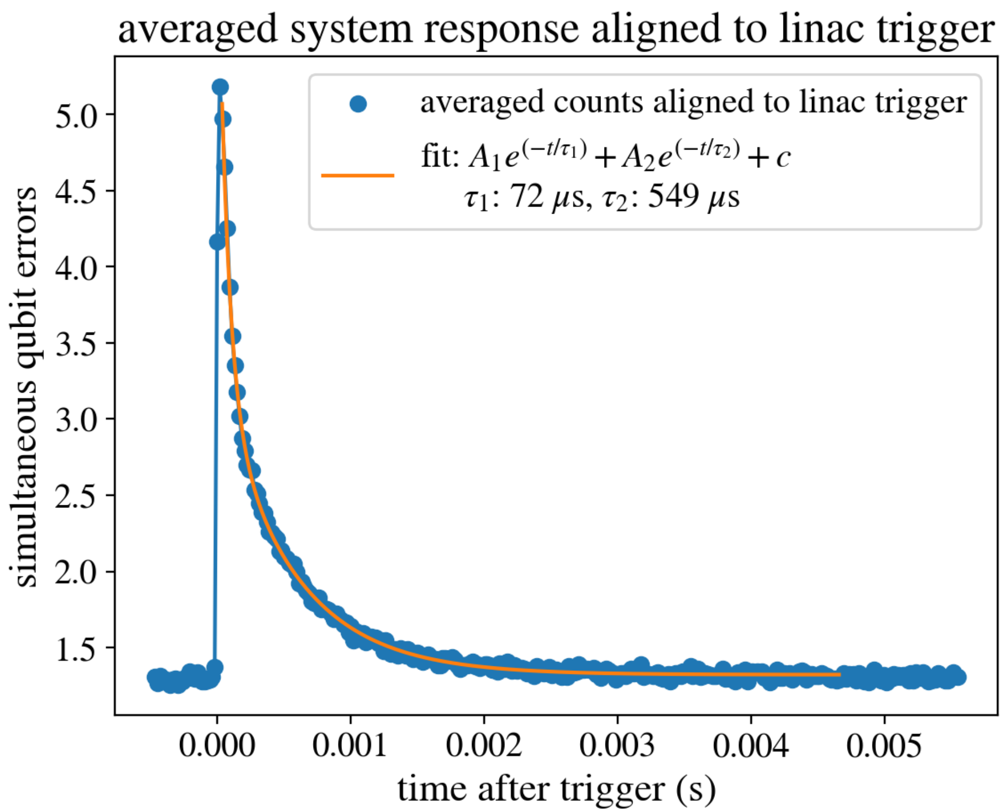
Wait a duration << T1

Correlated error events coincident with linac firing.

Single Event



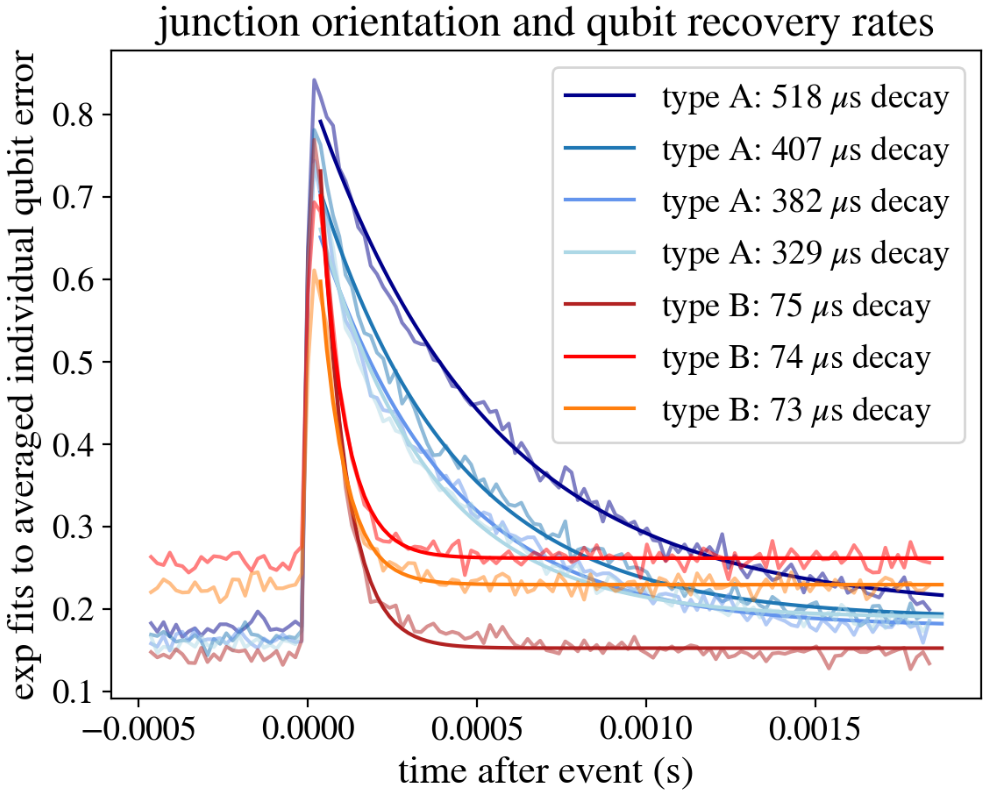
Averaged Events

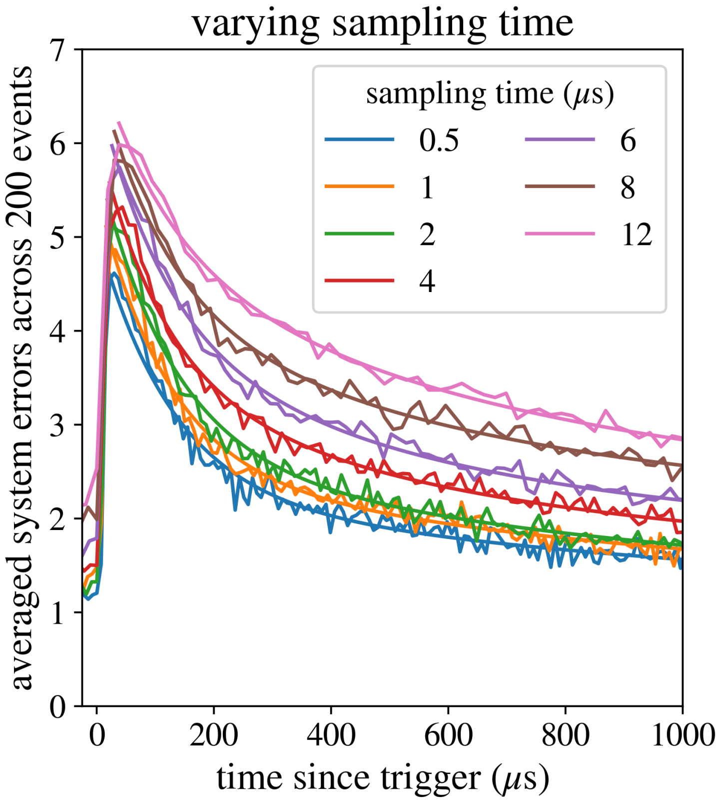


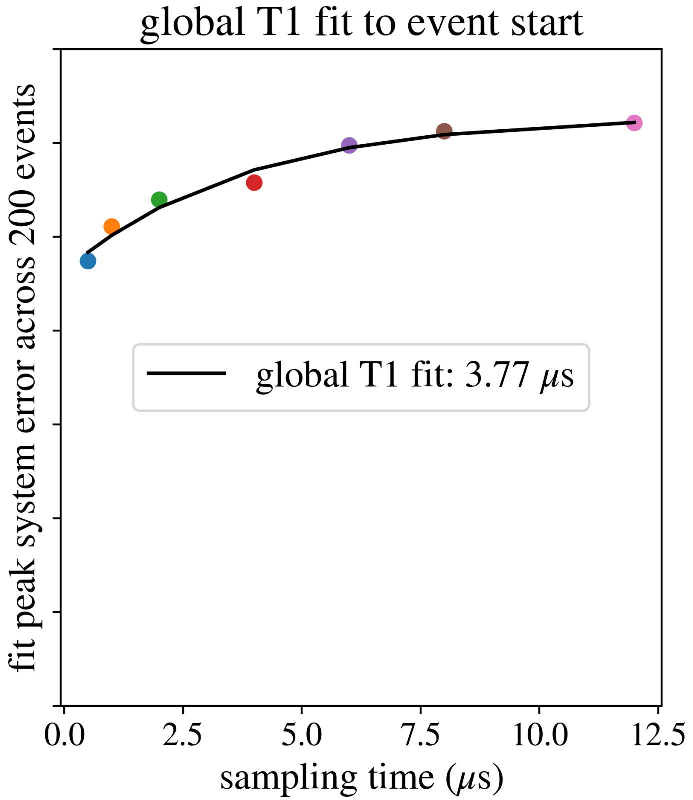
With a linac at 100 Hz, thousands of events can be recorded in minutes.

Linac trigger timing allows for easy extraction of averaged event behavior.

Detailed single-qubit and system response information is easy to collect and analyze.





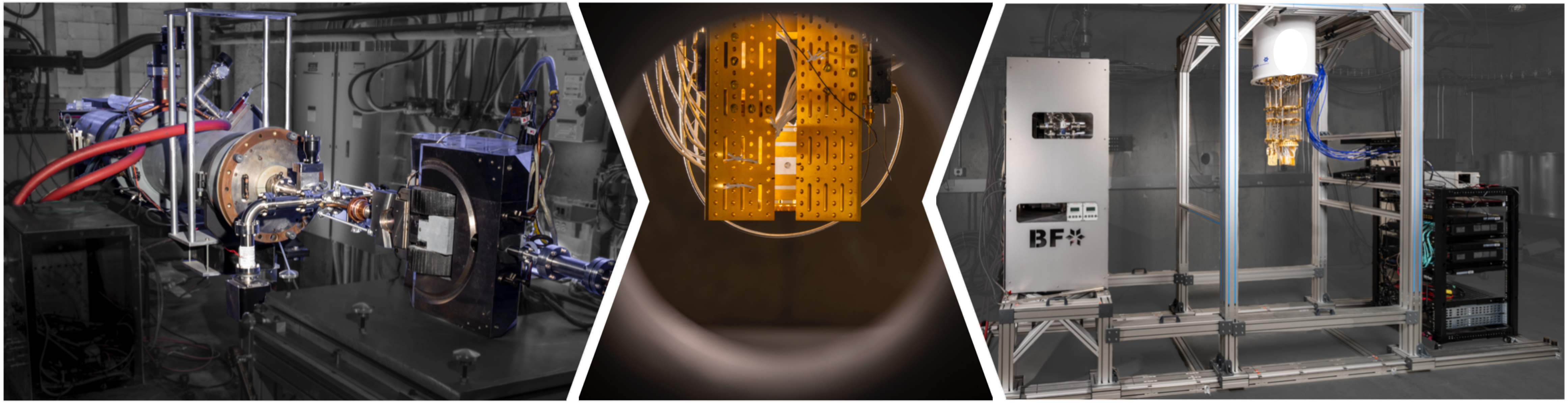


As shown in [1], junction orientation and gap differences affects qubit recovery.

As shown in [2], the event peak T1 can be extracted by varying sampling time, showing a 10X reduction in T1.

Review: APL facility provides a new method for studying radiation in quantum systems.

- Fast multi-qubit measurement combined with precise linac timing allows for rapid detection and analysis of high-energy impact events.
- Next steps: Validate technique with the beam redirected at qubits (muon surrogate) and vary the energy deposition.
- Future plans: Test other systems to explore mitigation techniques (qubit design, chip design, package thermalization, etc.).



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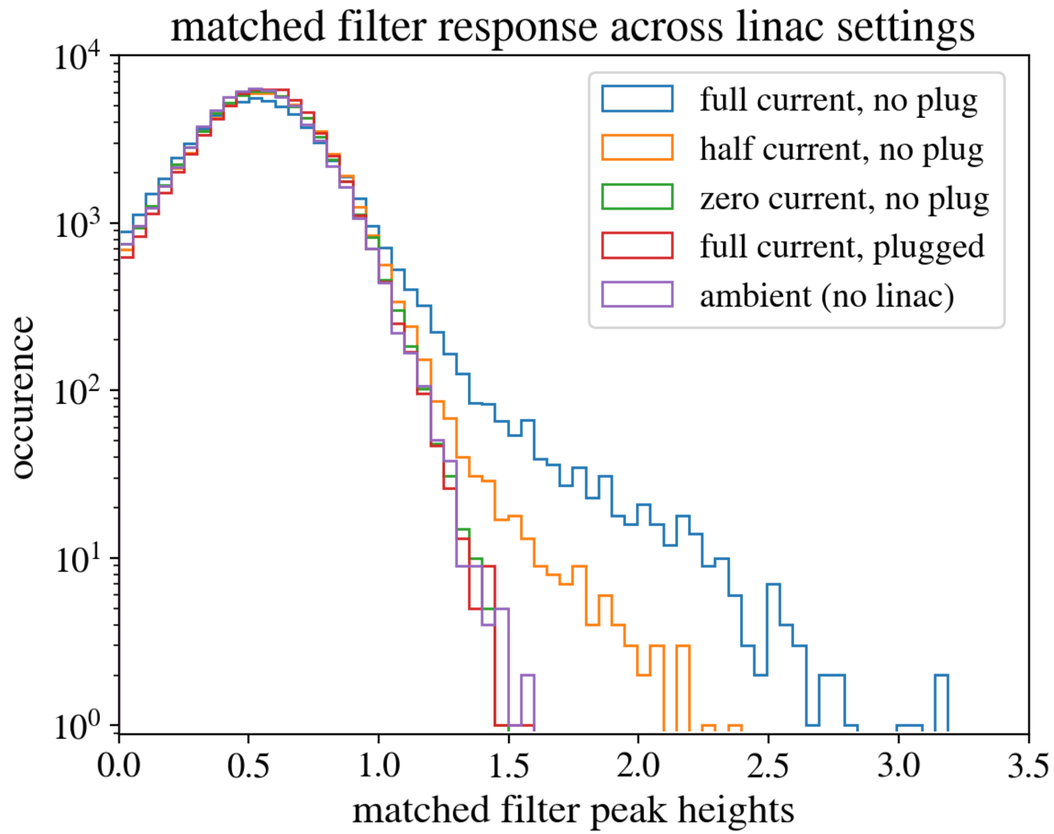
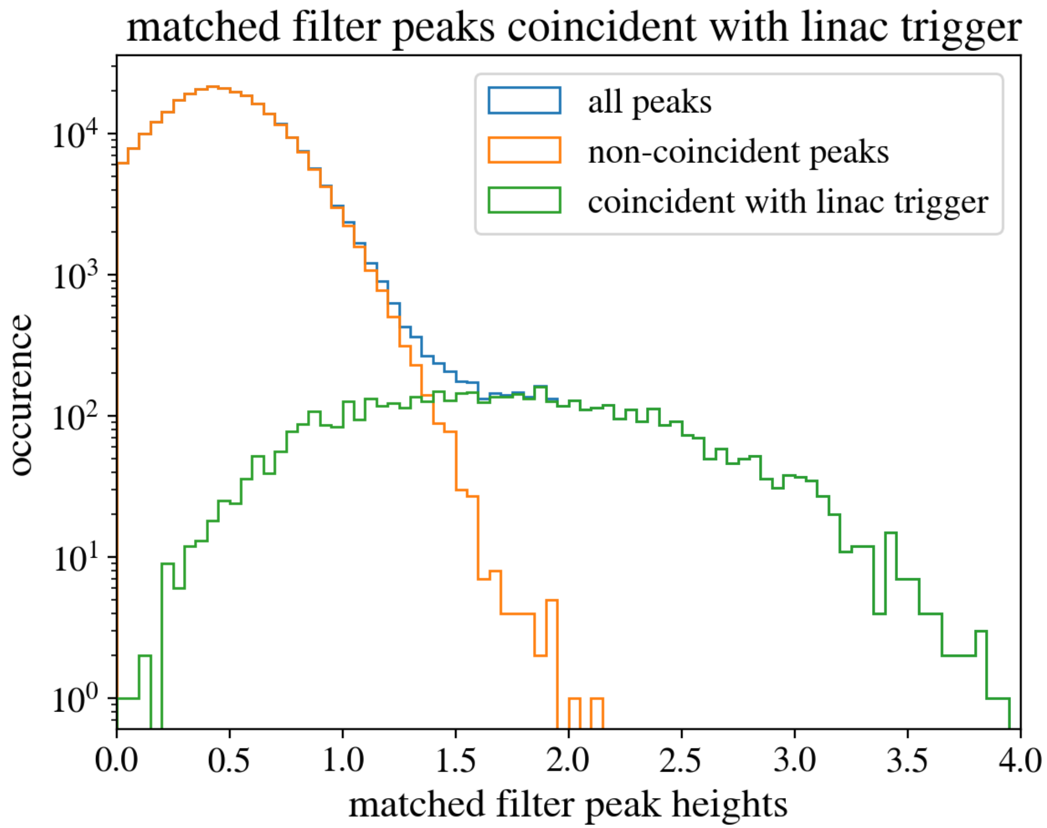
Backup: Validations of experimental techniques.



Varying the linac current and room conditions produces expected changes in qubit response.



Large-signal events are exclusively coincident with the linac firing.

Backup: Qubit recovery is dependent on state prep.

- Use of the linac (frequent, heralded events) makes qubit excitation from QPs (inherently less frequent) more visible.
- When qubits are prepared in the ground state (prep-0) instead of the excited state (prep-1), the recovery times of the two junction orientations flip.
- This phenomenon follows our understanding of QP densities in each junction layer and expected tunnel rates [1].