Operating qubits as particle detectors with QICK

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Qubits as particle detectors

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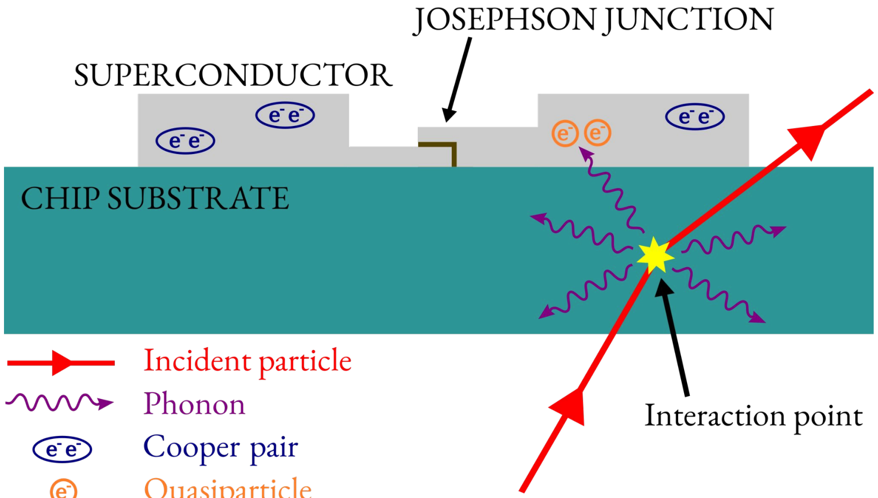
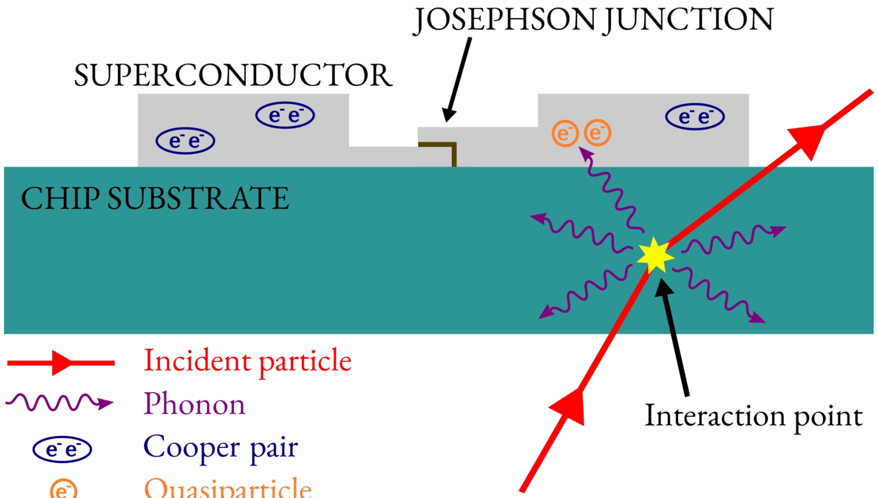
- Superconducting qubits are sensitive to the tunneling of broken Cooper pairs, also named *quasiparticles*, through the Josephson Junction;
- The decay rate of the qubit increases linearly with the density of quasiparticle in the superconductor.

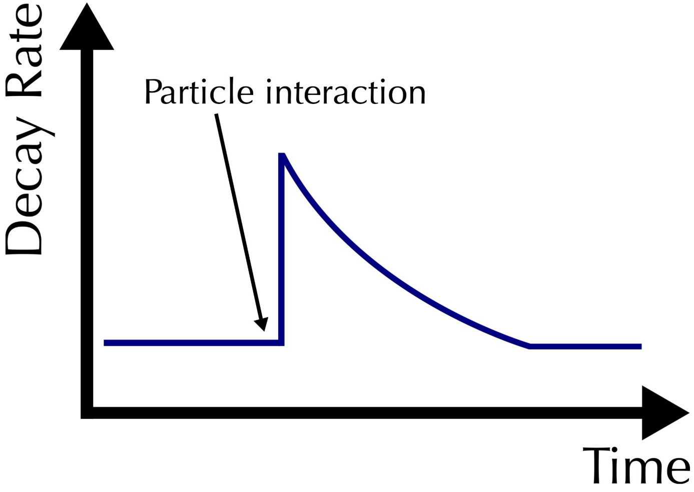


Qubits as particle detectors

- By interacting with the chip substrate, radiation produces phonons that can reach the superconductor and break Cooper pairs;
- Since the binding energy of Cooper pairs is O(meV), qubits can be very sensitive to radiation ⇒ they could be used as particle detectors!



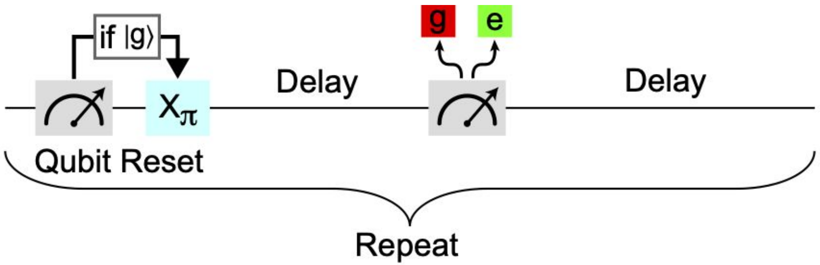
Qubits as particle detectors

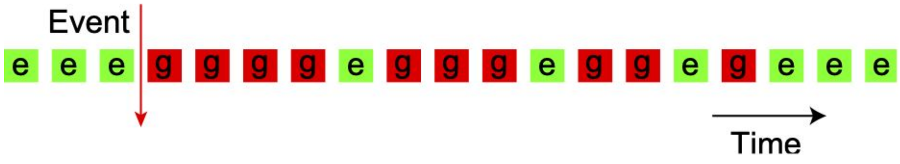


- After the particle interaction, the quasiparticles produced will recombine and the qubit behavior will go back to normal;
- The recombination happens with O(ms) timescales;
- A “classical” measurement of the energy relaxation time T_1 lasts tens of seconds, so it is not suitable for our purposes;
- We need a measurement which is much faster in order to observe events in the chip.

Measurement scheme

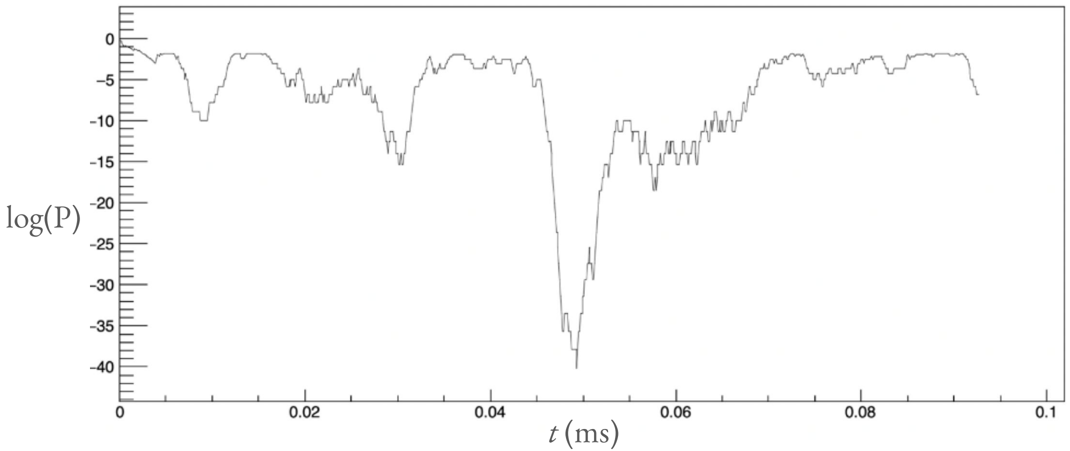
- Prepare the qubit in $|e\rangle$:
  - Measure the qubit state;
  - If the qubit is in $|g\rangle$ do nothing;
  - If the qubit is in $|e\rangle$ send a π-pulse to excite it;
- Measure its state after 5 μs;
- If a particle impact occurs we see an excess of measurements of the qubit in $|g\rangle$;
- An entire cycle is performed in < 100 μs.





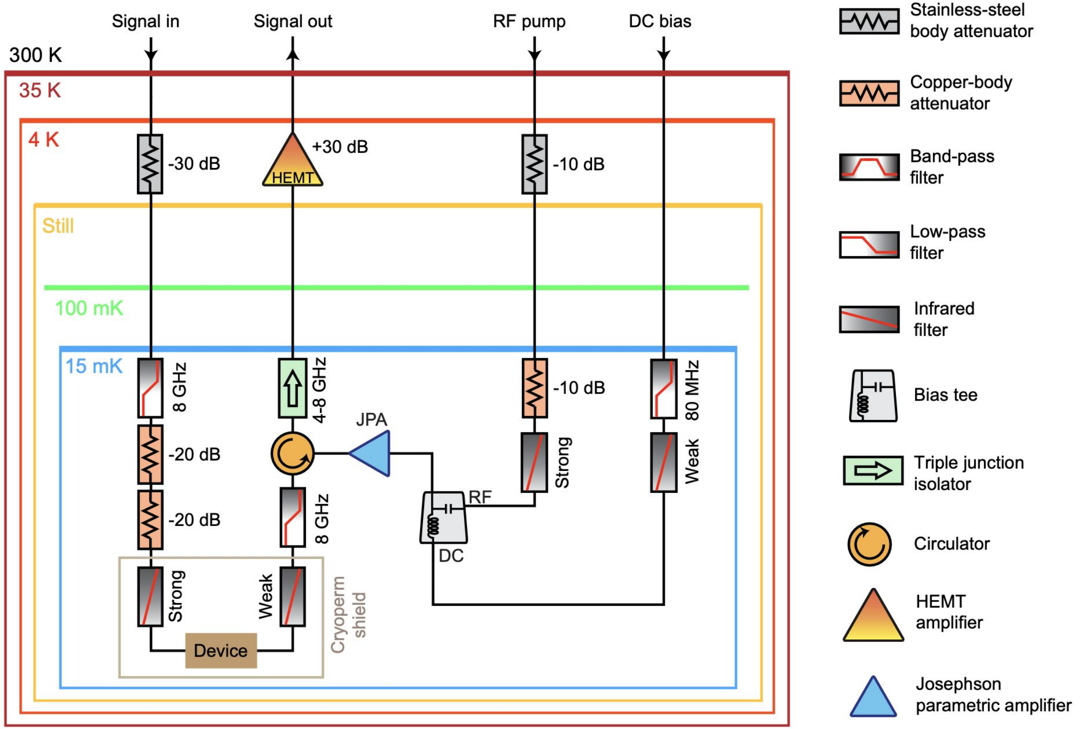
Measurement scheme

- Given a sequence of $|e\rangle$ and $|g\rangle$ measurements, we compute the logarithm of the probability P to observe that sequence given the characteristic decay time of the qubit;
- Particle interactions produce strong peaks in the time evolution of $\log(P)$:



Experimental setup

- Pulses are produced with a Zynq ZCU216 board;
- The board is controlled with the QICK package;
- A second package, QICKUtils, developed by FNAL, is used for sending instructions to QICK and store the data;
- Data analysis is done offline.



Preliminary results

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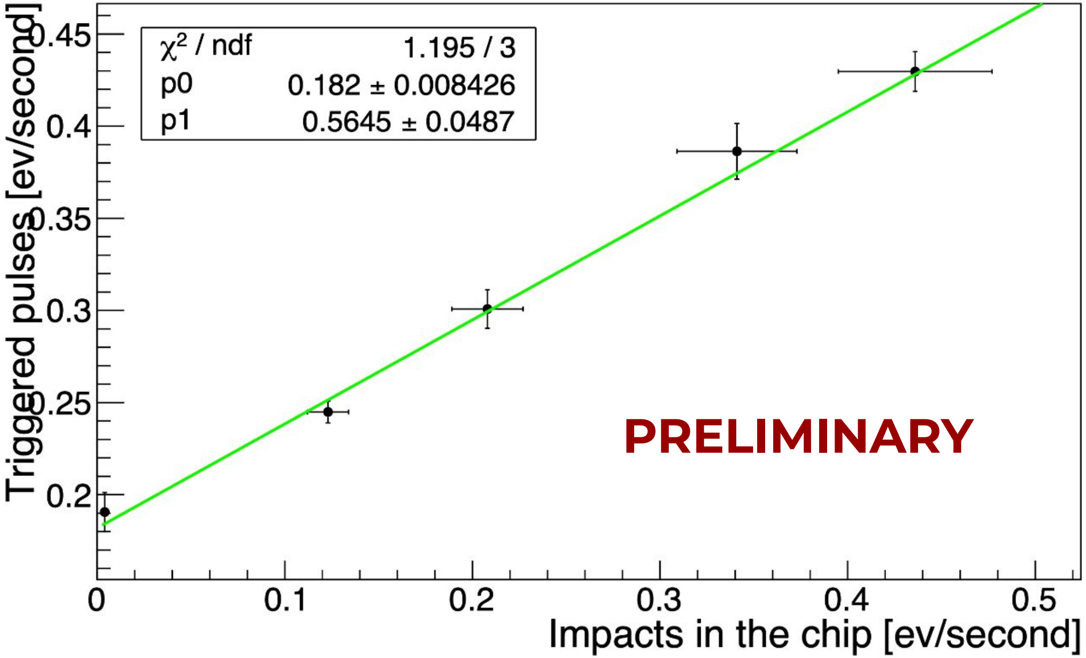

Run	Rate [mHz]
Bkg	191 +/- 11
44 kBq	245 +/- 6
76 kBq	301 +/- 10
125 kBq	386 +/- 15
161 kBq	430 +/- 11

Next steps

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- Measurements on a single qubit are very sensitive to errors in the qubit initializations or fluctuations in its decay rate;
- We are currently working on implementing the simultaneous readout of multiple qubits to perform a measurement of correlated errors and overcome this issue;
- We will also try to do our measurements by changing the type of source used, to collect informations on the energy threshold of the qubit.

Conclusion

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- We managed to operate the qubit as a particle detector;
- Detection, though, is strongly affected by noise;
- We are now working on simultaneous readout to reduce this noise and we plan to use different sources to investigate further the energy threshold of the qubit.