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Progress Towards Correlating Qubit Relaxation Events with Cosmic Rays

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Quantum Computing, Quantum Sensing, and Particle Detection

We implement Superconducting Qubits, and explore their capabilities as particle detectors. Our goal is to understand how qubits respond to cosmic ray interactions in the device substrate. In particular, we aim to improve the understanding of the underlying physics that causes relaxation. Future work aims to further develop this understanding, and leverage it to improve the sensitivity of qubit-based particle detectors.

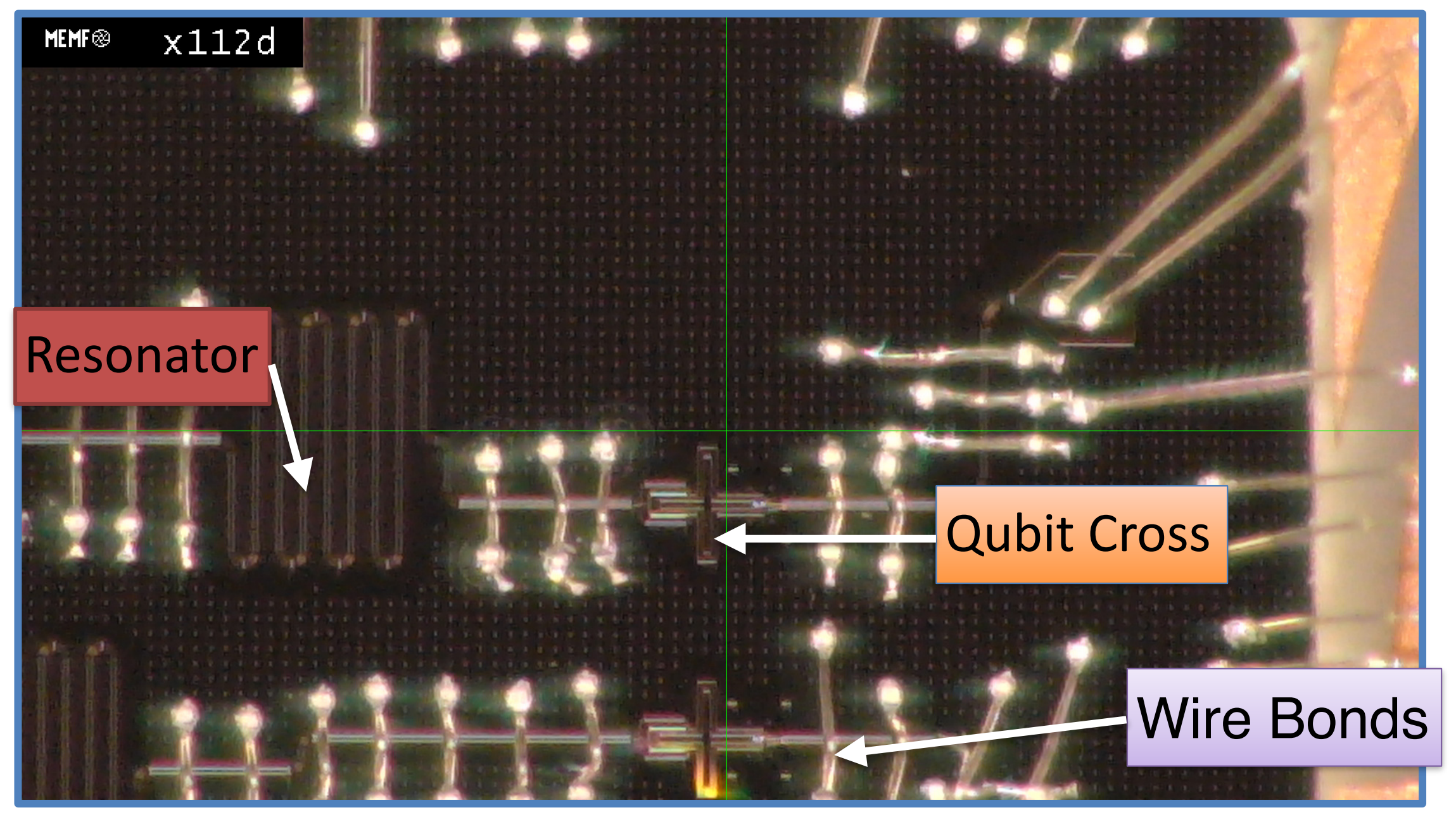
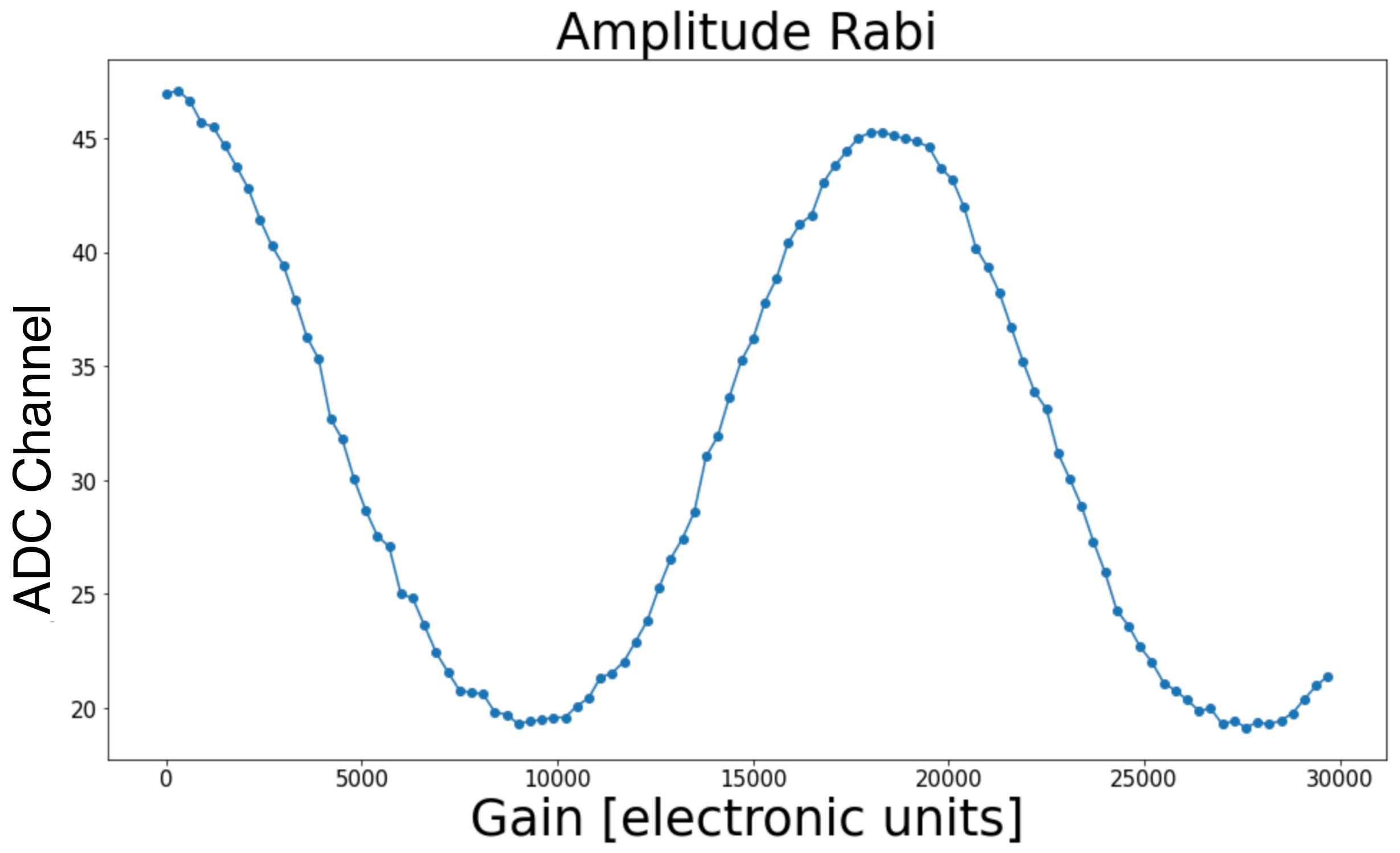


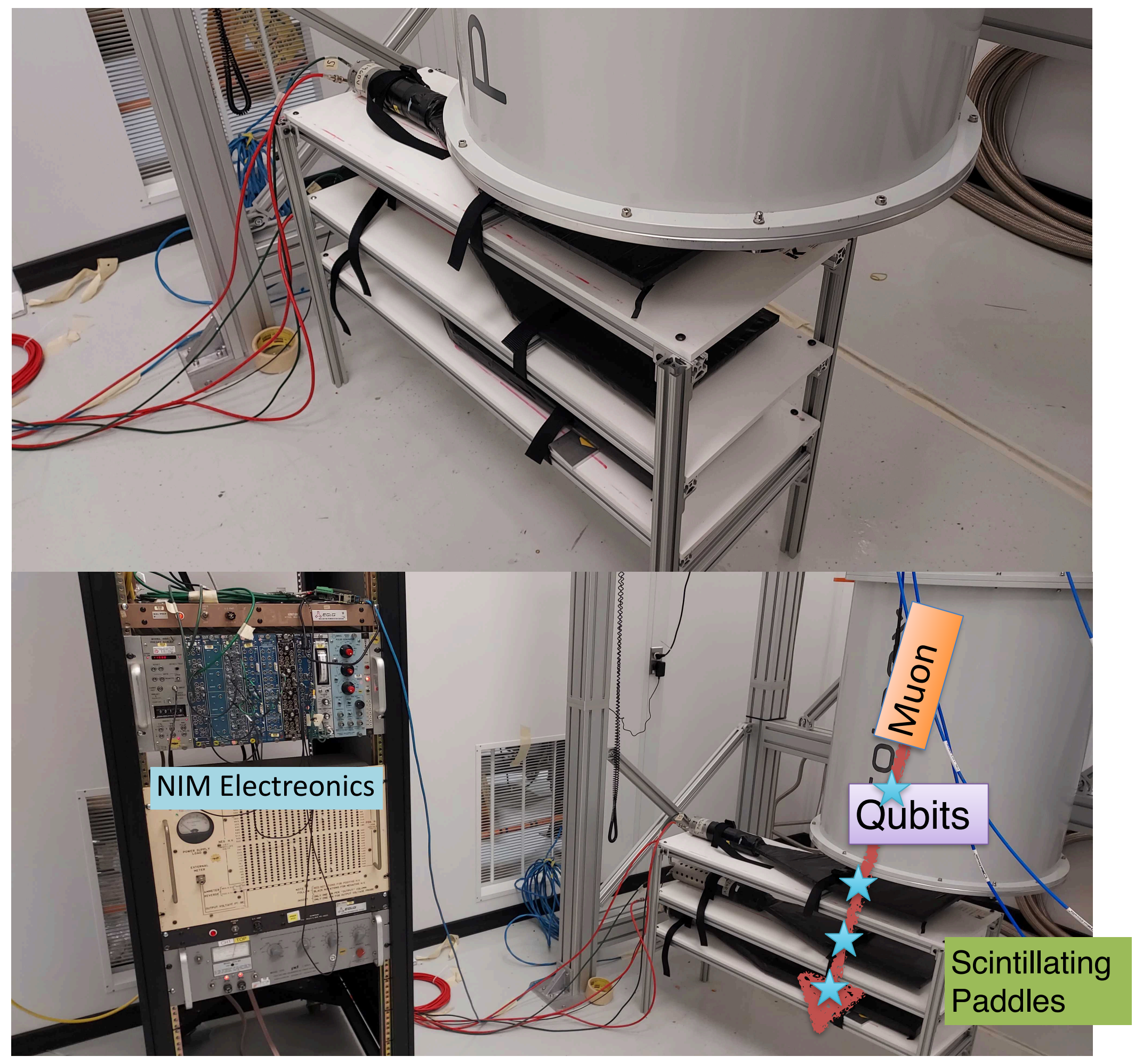
Image of the Qubit Chip we are working with. Here you can see the resonators (the long curved structures), the many wire bonds on the sides connecting the ground plane externally, and the qubit cross. This chip contains 6 qubits, though not all are pictured.



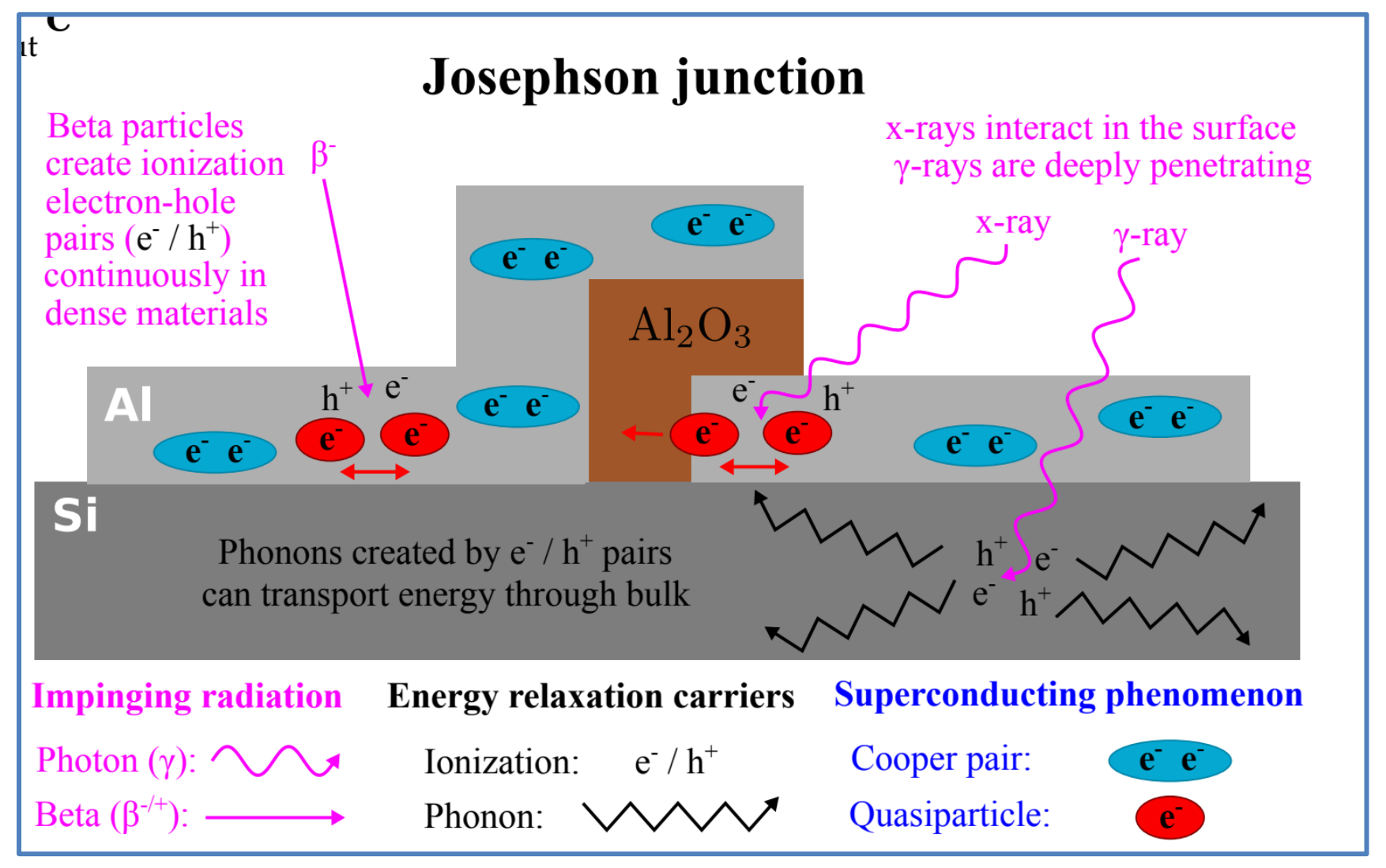
An Amplitude Rabi, demonstrating the one of the 6 qubits. The qubit excitation frequency is 5.776 GHz. The Y-axis here is the measured amplitude (transmission) of our resonator pulse, in electronic units. This amplitude maps to dBm as a function of gain and frequency. Physically, we are driving the qubit between it's 0 state, and 1 state, and by averaging many measurements together, we get this continuous curve.

Muon Detection

One key component of this project is to deploy a detector system able to tag cosmic ray muon events. This work is an extension of a previous SULI intern, Simon Mork, who designed and implemented the analog electronics. The muon detector works by triggering on events producing coincident scintillation in three scintillator paddles. These paddles are placed into a support structure, and positioned underneath an Oxford Proteox dilution refrigerator, where the qubit device is deployed. When an event is triggered, the NIM electronics send a 1 volt pulse to a digitizer card attached to a raspberry pi. A time stamp of this event is saved on the pi, with ~10 μs timing resolution, for offline correlation with qubit signals.



On the top, we stack three scintillating paddles top of each other. These are read out by the NIM in the electronics rack, visible on the bottom. For a given Muon collision, we require that it hits all 3 scintillating paddles within a time window of 10 ns. At this point the logic pulse is lengthened and sent to the raspberry pi, which achieves our 10 μs timing resolution. Additionally pictured is a mock path of a muon, demonstrating the ability to detect coincidence.

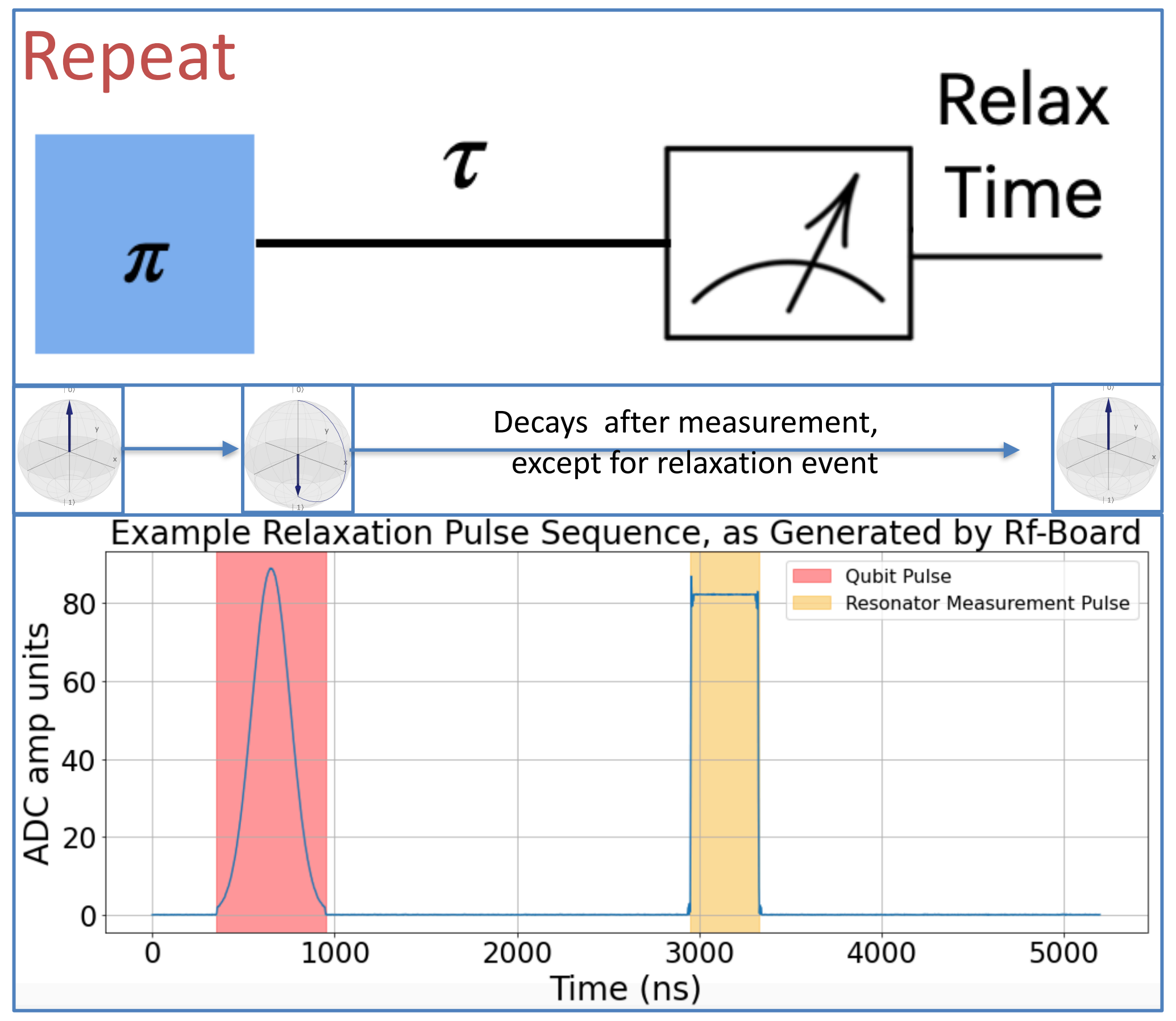


Vepsäläinen et al, Nature 584, 551–556 (2020)

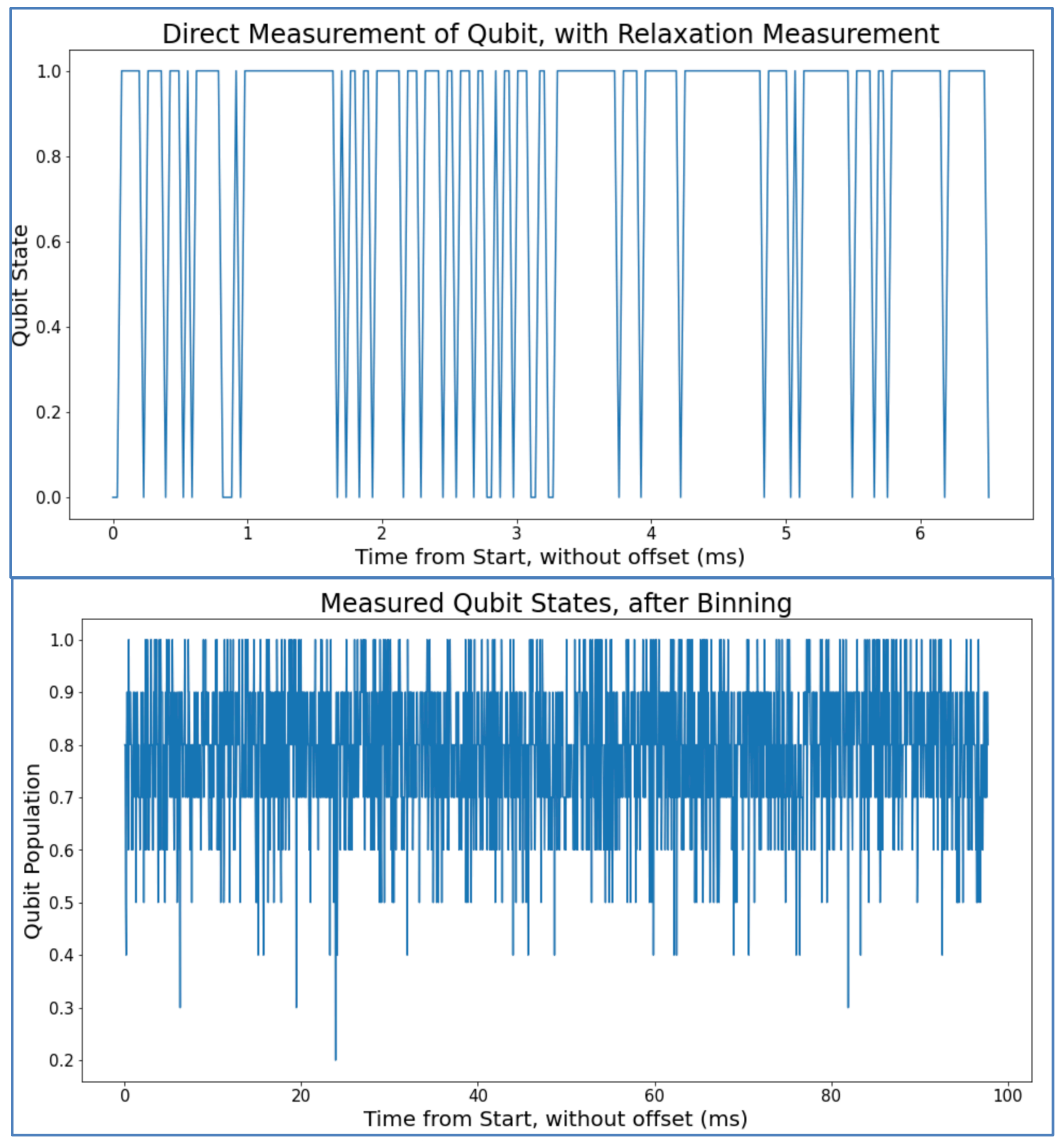
The probability that the qubit decays is given as $P_{decay} = e^{-\Gamma t}$, with $\Gamma = 1/T_1$. T_1 is an evaluation of how effectively the qubits retain information. To the left is a diagram showing how quasiparticle poisoning impacts qubits, and in particular Josephson junctions. The central idea is that quasiparticles take the qubits energy as they tunnel across the Josephson Junction. This tunneling effect follows the form $\frac{1}{T_1} \propto x_{qp}$, where x_{xp} is quasiparticle density. The relaxation mode aims to be sensitive to changes in this relaxation rate.

While there are multiple ways to operate a qubit as a sensor, we operate ours as a relaxation sensor, effectively creating a quasiparticle monitoring system. The best understanding of this can be seen in the left picture above, where quasiparticles cause decay errors. This is what we call a relaxation event, when some process causes a faster rate of decay from excited to ground. This relaxation rate is often called T_1.

To monitor this, we apply the circuit below. By placing our qubit in the excited state and measuring after τ, we can construct a waveform with high resolution (~10 μs). Interactions in the substrate should lead to ~1 ms disruptions in relaxation time, giving hopefully leaving a recognizable signal, which we are trying to identify now. In future work, we will combine these systems, so that we can correlate events in the qubit chip to muon events.



This is the readout method for our qubits, to operate it as a relaxation sensor. We tune our τ and relax time to be as sensitive as possible. The qubit is put into |1> by the pi pulse, and we measure if it remains there or decays. In a relaxation event, an increased quasiparticle density will create a much higher rate of errors.



On the top is a picture plot of the direct measurements from the relaxation measurement, where we directly receive 0s and 1s. We then bin (10) and average these data points, to generate the plot on the bottom. At the moment, we are working to improve noise. In order to correlate, we will measure both qubits and muon detectors simultaneously, storing timestamps, accurate to 10 μs, of both the qubit measurement and muon detector measurement. Further steps are being taken to fully understanding this readout, as well as improve it where possible. Current limiting factors are T1 (4.7 μs) and single shot fidelity (65%).

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