# Kinetics of Quasiparticle Tunneling in a Pair of Superconducting Qubits

**Matthew Shaw**
*University of Southern California*

**Roman Lutchyn**
*Joint Quantum Institute, University of Maryland*

**Per Delsing**
*Chalmers University of Technology*

**Pierre Echternach**
*Jet Propulsion Laboratory, California Institute of Technology*

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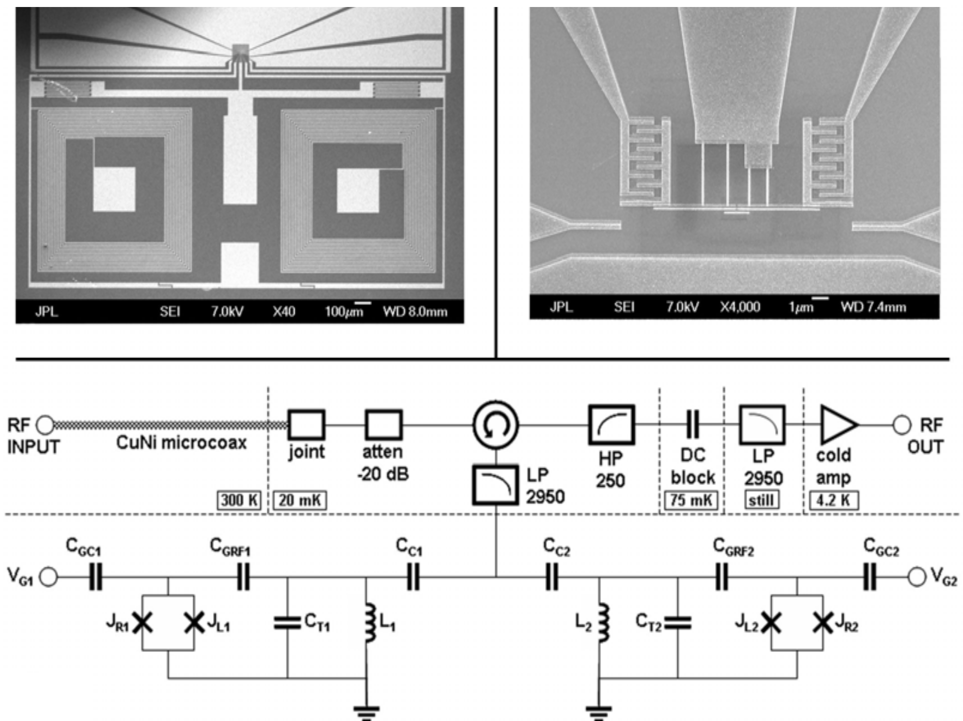
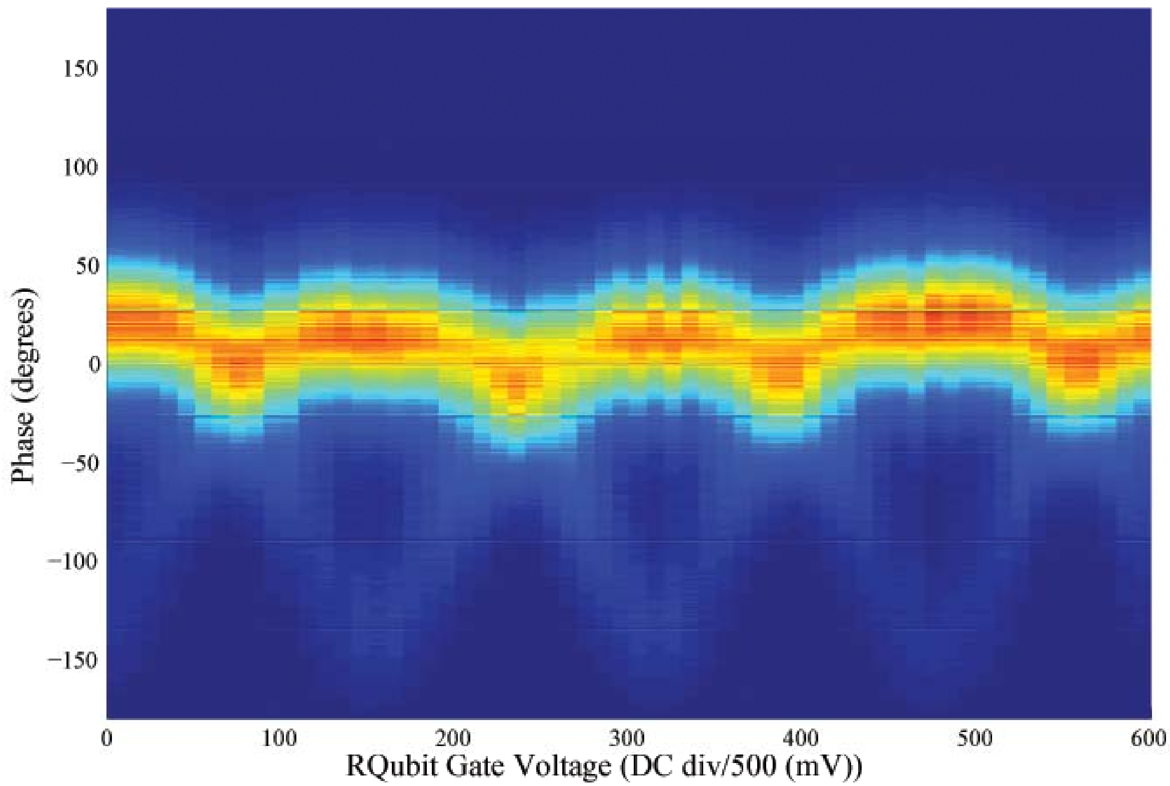
# Experimental Setup




- Qubits are based on the Single Cooper-pair box
- Two weakly coupled qubits, can be considered independent
- Multiplexed quantum capacitance readout scheme

# Quasiparticle Tunneling




- Low-temperature quasiparticles are not well understood
- Quasiparticle tunneling can be directly observed in the time domain
- QCR phase shift exhibits telegraph noise
- Odd-to-even and even-to-odd transition rates can be extracted independently
- Data can be understood in terms of a kinetic theory
- Understanding Nonequilibrium QP tunneling is essential for qubits

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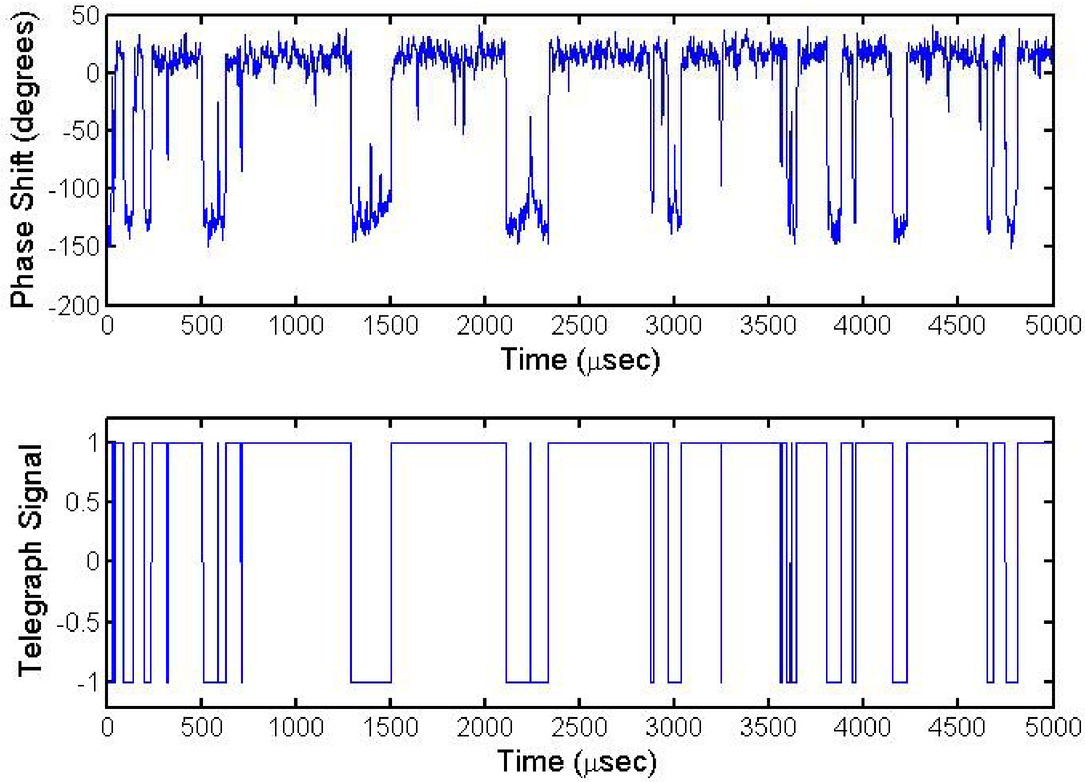
# Dwell Time Extraction




- Data record is 1s long, $10^6$ points
- Filtered with Schmitt trigger
- Dwell times extracted and binned into histogram

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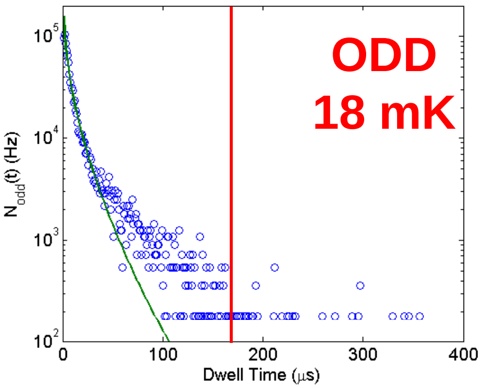
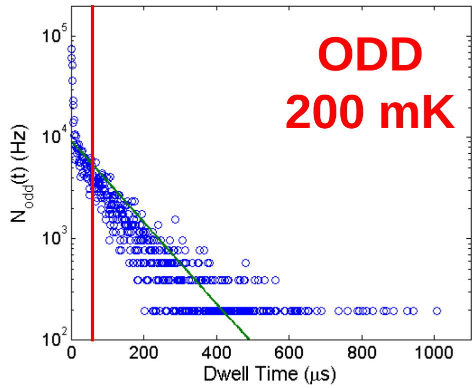
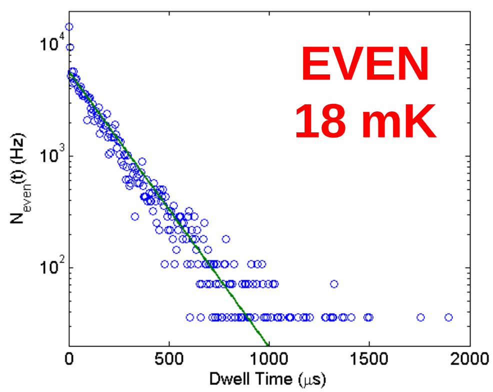
# Dwell Time Histograms

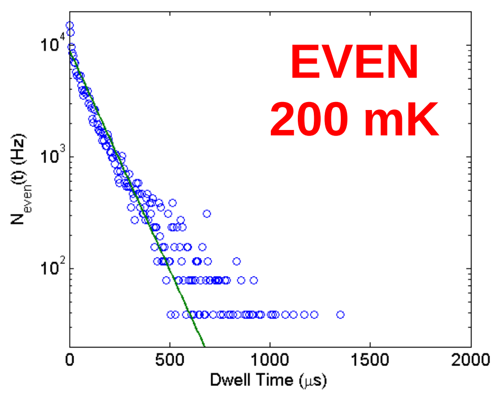



Odd-to-even rate ~ 52 kHz at 18 mK

$$N_{odd}(t) \approx \frac{2^{4/3}}{\sqrt{3}} \frac{\Gamma_{oe}^{N}}{\left(\Gamma_{oe}^{N} t\right)^{1/3}} \exp\left( -3 \left( \frac{\Gamma_{oe}^{N} t}{2} \right)^{2/3} \right)$$




Even-to-odd rate ~ 5 kHz at 18 mK
at degeneracy point

$$N_{even}(t) = \Gamma_{eo} \exp\left(-\Gamma_{eo} t\right)$$

Odd-to-even dwell time distribution is non-Poissonian

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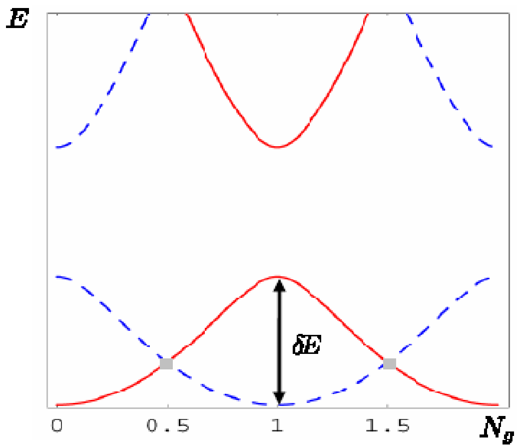
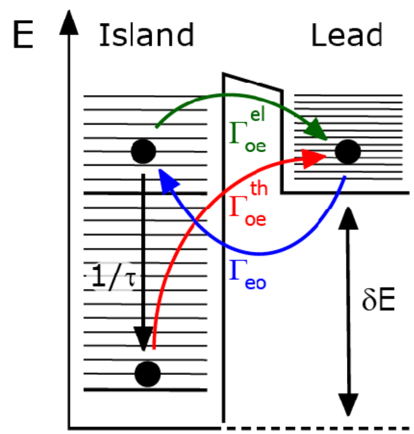
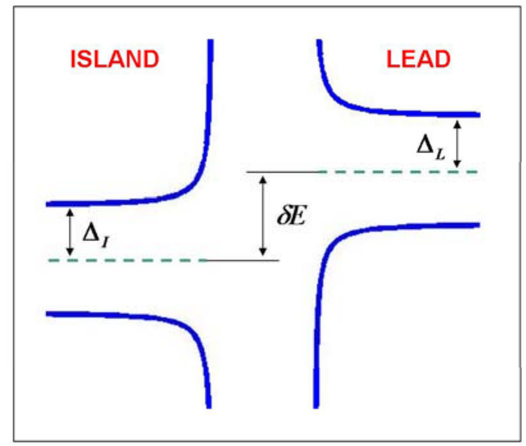
# Kinetic Theory



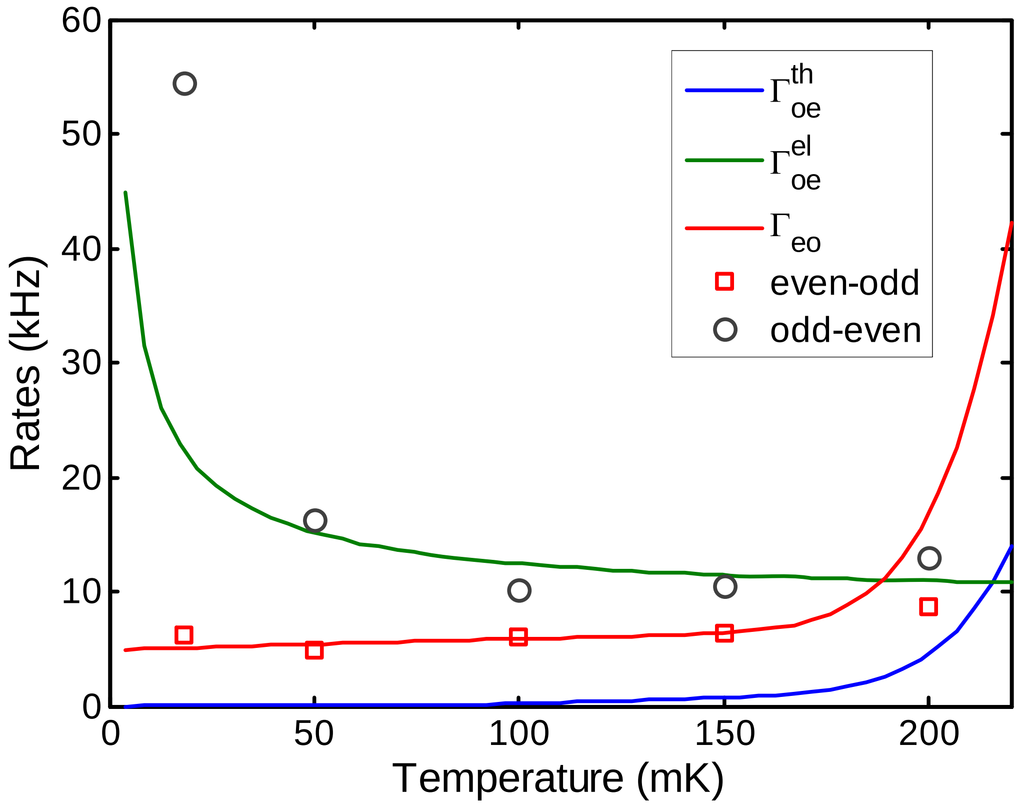




$$\Gamma_{oe} = \frac{G_N}{e^2}\int_{-\infty}^{\infty} dE \, \frac{1}{2}\left(1 - \frac{\Delta_I \Delta_L}{E(E+\delta E)}\right) g_L(E) g_I(E+\delta E)\left(1 - f(E-\delta\mu_L)\right) f(E+\delta E-\delta\mu_I)$$

destructive interference ⟶ $\left|\langle n+1|H_T|n\rangle + \langle n+1|H_T|n+2\rangle\right|^2$

R. Lutchyn and L. Glazman, PRB 75, 184520 (2007)

# Temperature Dependence




$$\Delta_I = 2.5K$$

$$\Delta_L = 2.6K$$

$$n_{qp} = 7\times10^{-20}m^{-3}$$

- Model predicts qualitative features of the data
- Predicts sharp rate increase at low temperatures
- Destructive interference term is necessary
- Direct experimental verification of Lutchyn's model

# Conclusions

- Quasiparticle tunneling can be understood at low temperatures using a nonequilibrium kinetic theory
- Low-temperature tunneling can be suppressed using existing techniques
  - Island-lead gap engineering
  - Lead cooling with SIN junctions
  - Quasiparticle traps
- Problem contains some interesting physics

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