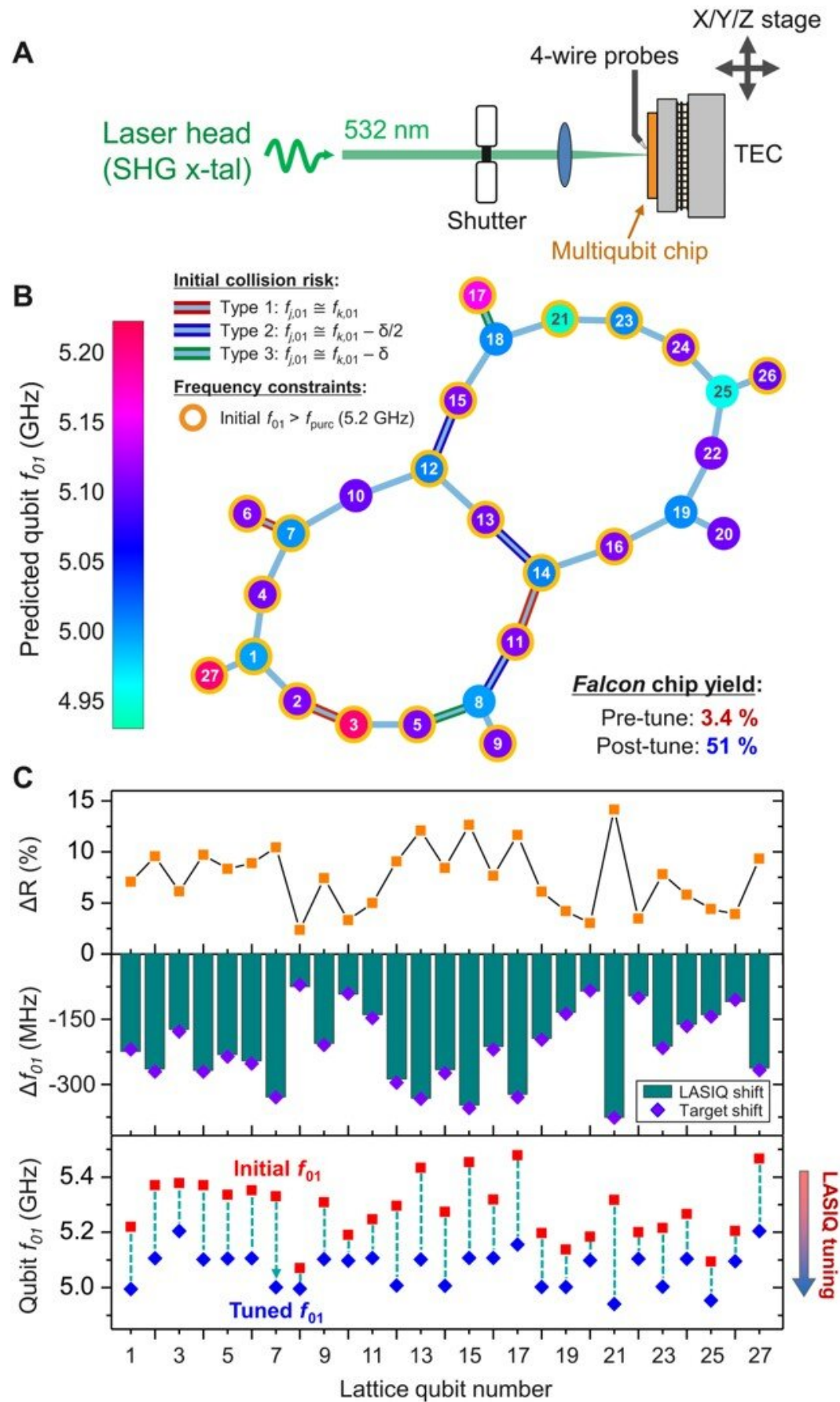


Laser annealing transmon qubits for high-performance superconducting quantum processors

May 19 2022, by Thamarasee Jeewandara



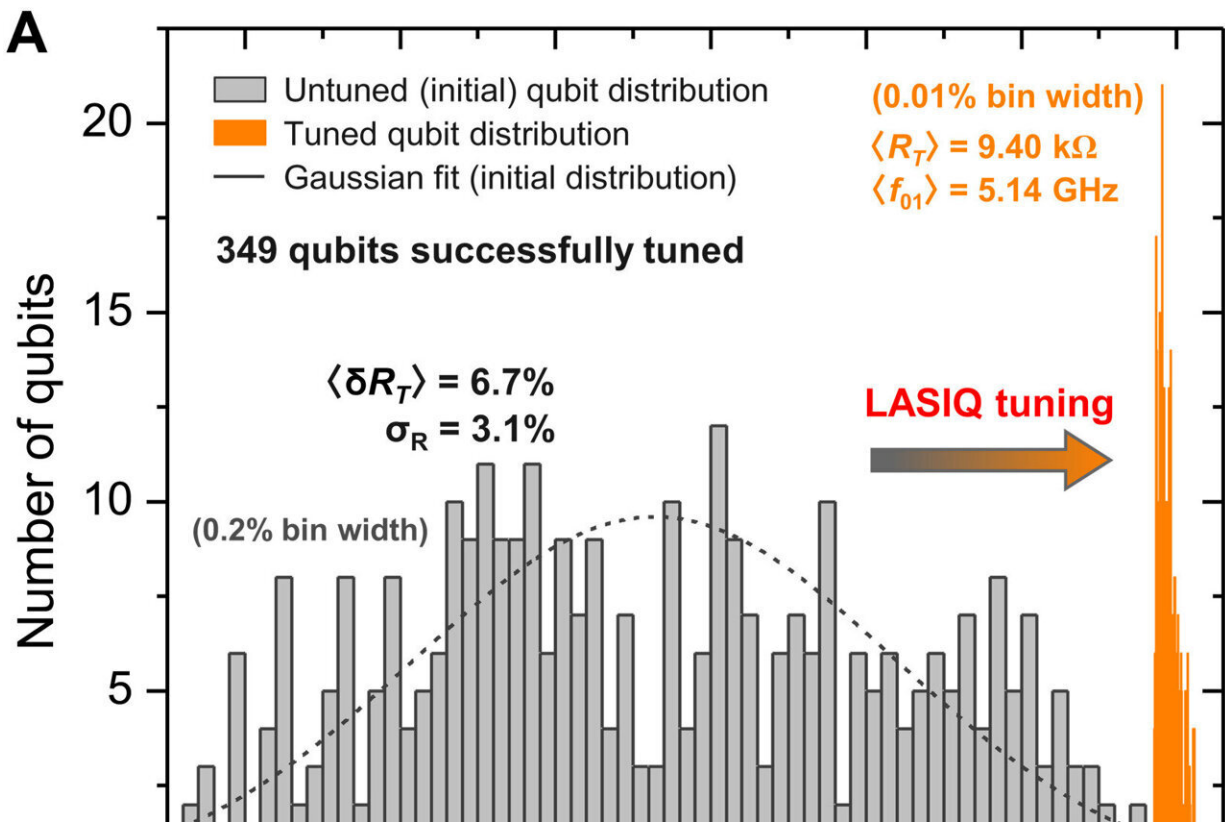
Example of a LASIQ anneal process. (A) Outline of the laser trimming setup (23). A 532-nm second-harmonic generation laser is sequentially focused on the junctions of a multiqubit quantum processor, with thermal annealing to selectively decrease qubit frequencies (f_{01}) for collision avoidance. (B) Example of a tuned 27-qubit Falcon lattice. Final predicted f_{01} are depicted as a heatmap, with initial high-risk NN collision pairs highlighted, and orange outlines indicating initial f_{01} above the bandwidth of Purcell protection. After LASIQ, collision and frequency constraints are resolved. (C) Detail of qubit anneals. The bottom panel indicates the initial (red) and final (blue) predicted f_{01} showing the qubits tuned to distinct frequency set points. The middle panel indicates the tuning distance (monotonic negative shifts), along with the desired target shifts (purple diamonds), with an RMS deviation (i.e., frequency-equivalent resistance tuning precision) of 4.8 MHz, as determined from empirical $f_{01}(R_n)$ correlations. The top panel depicts the corresponding junction resistance shifts, achieving tuning ranges up to 14.2%. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abi6690

Quantum physicists aim to scale the number of [qubits](#) during quantum computing, while maintaining high-fidelity quantum gates; this is a challenging task due to the precise frequency requirements that accompany the process. Superconducting quantum processors with more than 50 qubits are currently actively available and these fixed frequency [transmons](#) are attractive due to their long coherence and noise immunity. A transmon is a type of a superconducting charge qubit designed to have reduced sensitivity to charge noise. In a new report now published in *Science Advances*, Eric J. Zhang and a team of scientists at IBM Quantum, IBM T.J. Watson Research Centre, New York, U.S., used laser annealing to selectively tune transmon qubits into the desired frequency patterns. The research team achieved a tuning precision of 18.5 MHz, without any measurable impact on quantum coherence, and

envision facilitating selective annealing in this way to play a central role in fixed-frequency architectures.

Laser annealing of stochastically impaired qubits (LASIQ)

Multi-[qubit](#) systems can be built on superconducting circuit quantum electrodynamics architectures for a variety of applications, including implementing [Shor's factoring algorithm](#), [quantum chemistry simulations](#) and [machine learning](#). Researchers have also used the metric of [quantum volume](#) to track the continual progression of quantum processing power [for a given processor](#). Quantum physicists had recently developed a technique for laser annealing of stochastically impaired qubits, abbreviated LASIQ to increase the collision-free yield of transmon lattices by tuning individual qubit frequencies via [laser thermal annealing](#). In this work, Zhang et al demonstrated the LASIQ process as a scalable method to obtain the expected laser tuning precision. In addition to the number of tuned qubits, they measured the functional parameters of multi-qubit chips for high processor performance. During the study, they explored the LASIQ scaling capabilities by tuning a [65-qubit Hummingbird processor](#) (accessible as `ibmq_manhattan`). Zhang et al. envision that the LASIQ process will be employed as a scalable [frequency](#) tuning tool for fixed frequency transmon architectures in future generations of superconducting quantum systems.

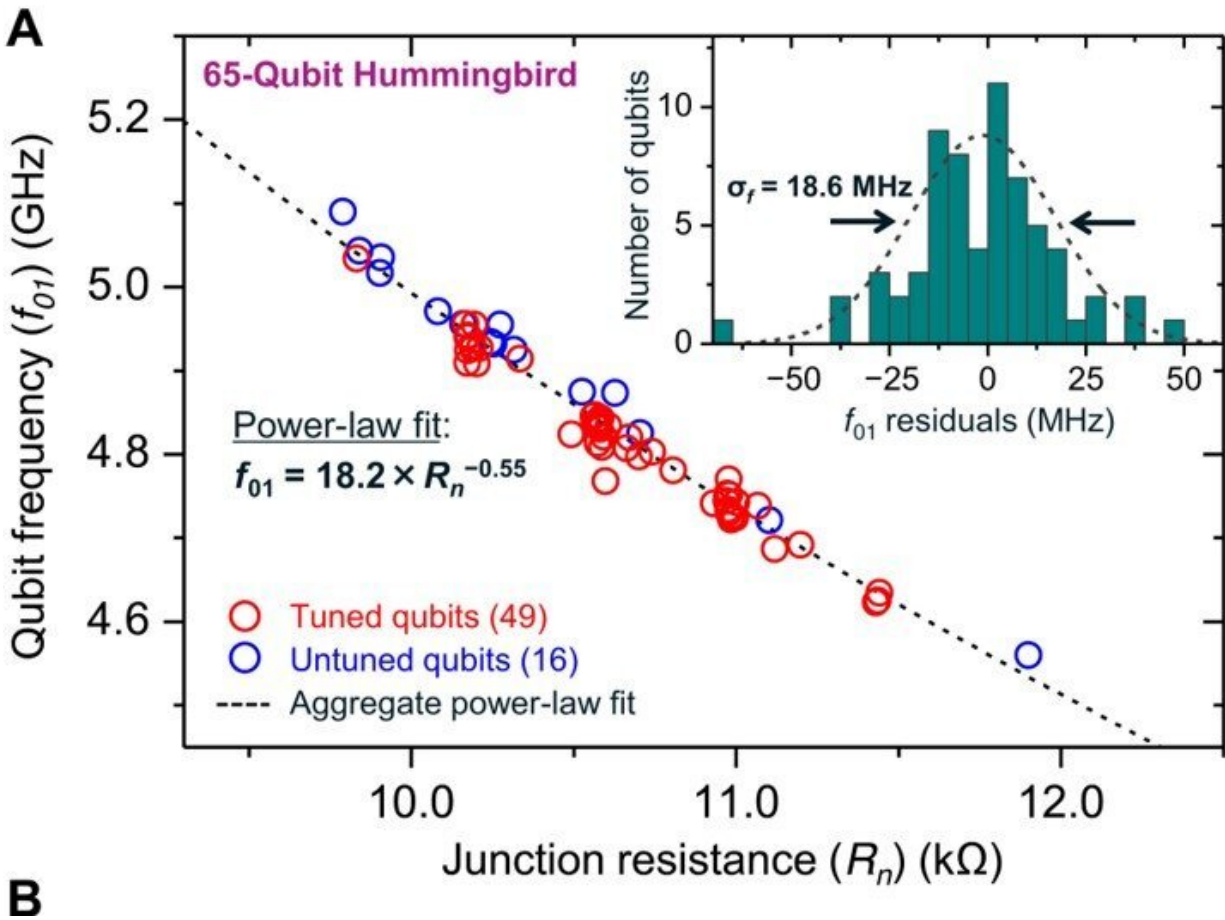


LASIQ tuning outcome statistics. (A) Initial distribution (gray) of qubits that were successfully tuned to target (orange). The distance from target δR_T is the tuning differential normalized to the final target resistance R_T . Orange bars indicate the final distribution (20 \times reduced bin width for clarity) and show the 349 qubits tuned to success. (B) Expanded view of the orange distribution shown in (A). Anneal success is defined as a tuned resistance within 0.3% of R_T , which was reached by all displayed qubits, and 89.5% of the 390 tuned qubits (details in the Supplementary Materials). The blue/red regions indicate undershoot/overshoot, respectively. A log-normal fit is shown by the black curve, which supports the interpretation of LASIQ tuning as an incremental resistance growth process. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abi6690

LASIQ tuning a 27-qubit Falcon processor and improving the tuning precision

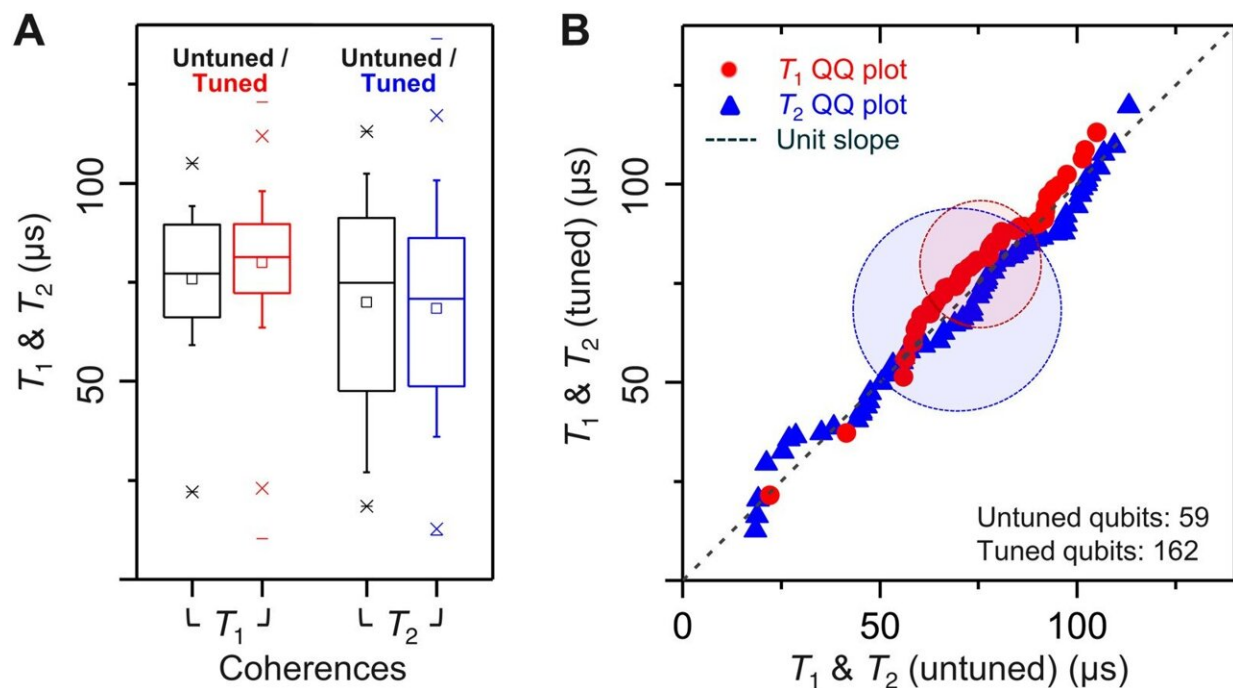
As proof of concept, the team showed frequency tuning with a [27-qubit Falcon processor](#) to predict frequency targets. They based the Falcon chip series on a [heavy-hexagonal lattice](#) and performed all measurements at ambient conditions to achieve tuned frequencies. The scientists evaded nearest neighbor collisions with [twice the collision tolerance](#) to improve chip yield against two-qubit state hybridization. In addition to avoiding collisions, the team tuned all targets to prevent [radiative qubit relaxation](#). After completing the LASIQ process, they cooled the quantum processor and screened for coherence and single or [two-qubit gate](#) fidelity, as well as [quantum volume assessment](#).

The scientists addressed the limits of LASIQ tuning precision as limitations of the process itself. For instance, when Zhang et al analyzed a large sample of 390 tuned qubits, 349 of them could be successfully tuned to target for a tuning success rate of 89.5 percent during the experiment. The work showed how LASIQ provided a viable post-fabrication trimming process for [high yield](#) scaling of fixed frequency transmon processors. The outcome offers more space to improve frequency predictions to reach greater tuning precision.



Frequency assignment precision based on statistical aggregates of tuned 27-qubit Falcon and 65-qubit Hummingbird processors. (A) Resistance (R_n) to frequency (f_{01}) correlation for a tuned Hummingbird processor. Cryogenic f_{01} measurements are plotted against measured junction resistances R_n , with a power-law curve superimposed on the measured data. Both tuned (49 qubits) and untuned (16) qubits are depicted. The inset shows a histogram of residuals with an SD of 18.6 MHz, indicating the practical precision to which we may assign qubit frequencies. (B) The top panel shows statistical precision analysis performed for a total of 241 tuned qubits from a combination of Falcon and Hummingbird chips, with aggregate f_{01} residuals from individual power-law regressions for each chip. The bottom panel shows identical analysis performed for 117 untuned qubits from both processor families. Cryogenic f_{01} measurements yield 18.5- and 18.1-MHz spread for tuned and untuned qubits, respectively, indicating that the LASIQ process does not significantly affect the overall spread of qubit frequencies before preparatory chip cleaning, bonding,

and cooldown processes. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abi6690

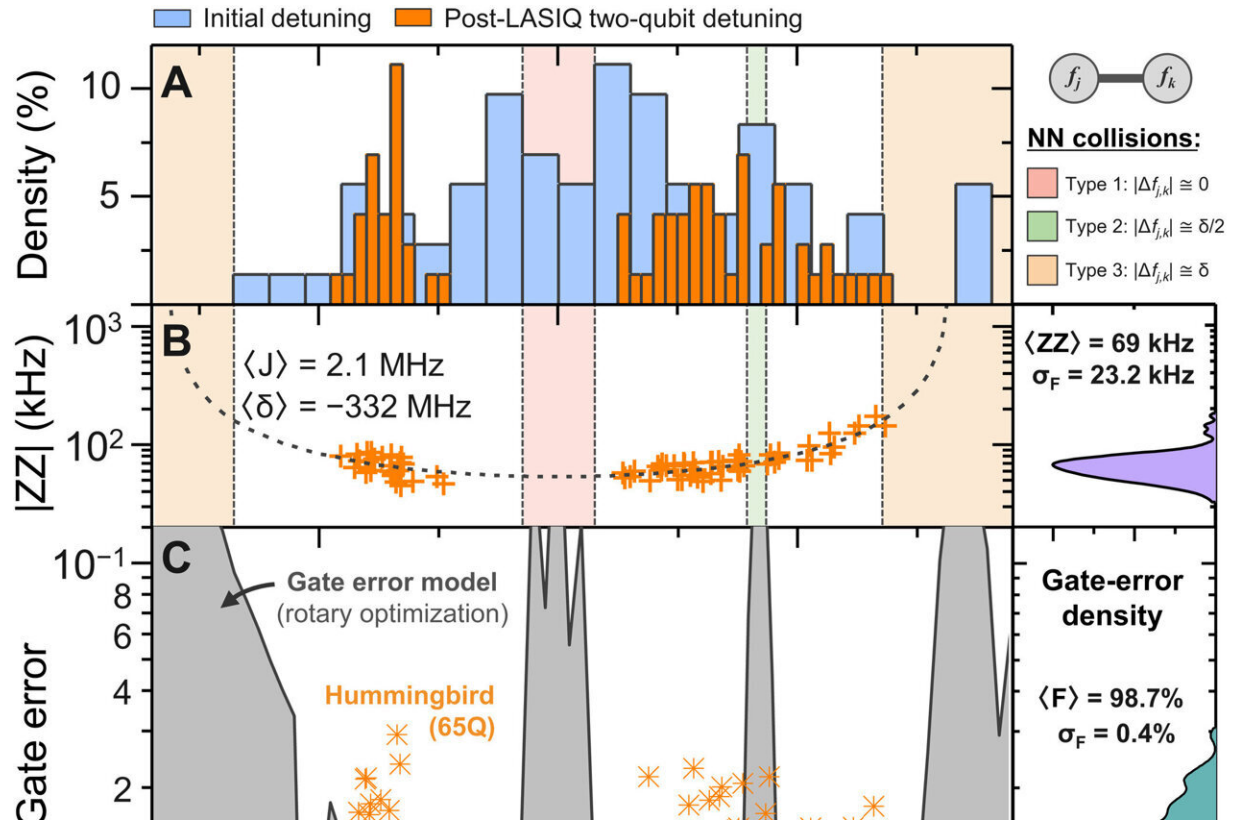


Impact of LASIQ tuning on qubit relaxation (T_1 , red) and dephasing (T_2 , blue), using composite (partially tuned) Hummingbird processors. Qubit coherences on four Hummingbird chips are analyzed. On each chip, both untuned and tuned qubits were simultaneously measured, for a total statistical sample of 59 untuned and 162 tuned qubits. (A) Box plots of T_1 and T_2 distributions (with interquartile box range, 10 to 90% whiskers, 1 to 99% outliers indicated by crosses and minima/maxima by horizontal markers). Coherence distributions show no statistically significant difference in untuned as compared with LASIQ-tuned qubit populations. (B) Illustrates this comparison as a quantile-quantile (QQ) plot of the T_1 and T_2 distributions. Each point represents a comparison between estimated quantiles from the set of 59 untuned qubits against the interpolated quantiles of the 162 tuned qubits. Good linearity with respect to unit slope indicates a close match of the coherence distributions in tuned and untuned qubit populations. Mean values agree robustly within statistical error bounds. For tuned (untuned) qubits, $\langle T_1 \rangle = 80 \pm 16 \mu\text{s}$ ($76 \pm 15 \mu\text{s}$) and $\langle T_2 \rangle = 68 \pm 25 \mu\text{s}$ (70

$\pm 26 \mu\text{s}$). The shaded ovals are centered on the mean coherence times and have 1- σ extent in relaxation and dephasing times. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abi6690

Qubit coherence and gate fidelity

In order to determine the effect of laser tuning on qubit coherence (a unique property of a quantum system), the scientists used a composite set of four cooled Hummingbird processors, and increased their coherence. They observed good correspondence, indicating a negligible effect of the LASIQ process on [qubit coherence](#). As a practical demonstration of the tuning capabilities of LASIQ, Zhang et al laser-tuned a 65-qubit Hummingbird processor, operationally cloud-accessible as `ibmq_manhattan`. They generated the LASIQ tuning plan by avoiding nearest neighbor level degeneracies, while maintaining level separation [in the straddling regime](#). The scientists cooled the 65-qubit processor after LASIQ and measured qubit frequencies with density of frequency detuning between two-qubit gate pairs. The outcomes generated a 100 percent yield of working [two-qubit gates](#), further work will determine the exact collision constraints and identify high-fidelity tuning regimes with progressively increased lattice sizes.



Gate errors of a 65-qubit Hummingbird processor after LASIQ tuning. (A) Distribution of tuned two-qubit f_{01} separation (orange), along with the initial (pre-LASIQ) distribution (blue), indicating high density of collisions and gate errors before LASIQ tuning. (B) Achieved ZZ distribution after LASIQ tuning, indicating well-tailored separation near null-detuning (type 1 NN collision), while maintaining a tight ZZ spread with 69-kHz median. A kernel density estimator (KDE) is used to calculate the ZZ probability density (right). (C) Measured CNOT (Controlled NOT) gate errors as a function of two-qubit detuning (orange points), yielding a median gate fidelity of 98.7% for the LASIQ-tuned Hummingbird (the corresponding KDE distribution of gate errors is shown on the right panel). The shaded (gray) regions indicate approximative error-rate projections based on CR gate error modeling (35), incorporating typical qubit interaction parameters (frequency and anharmonicity, qubit coupling, and gate times), with optional rotary echo pulsing for error minimization. Credit: *Science Advances* (2022). DOI: 10.1126/sciadv.abi6690

Outlook

In this way, Adam J. Zhang and colleagues, achieved significant yield improvement and high two-qubit gate fidelities for both Falcon and Hummingbird IBM quantum [processor](#) types. Based on the outcomes they highlighted the influence of LASIQ—laser annealing of stochastically impaired qubits; an affective post-fabrication frequency tuning method. The method can be applied to multi-qubit processes based on fixed-frequency transmon architectures. The method offers a scalable solution to the problem of [frequency crowding](#), with adaptability to scale qubits in progressively larger quantum processors. Future work will include tuning plans to minimize errors of near-neighbor collisions and spectator collisions for a maximized yield.

More information: Eric J. Zhang et al, High-performance superconducting quantum processors via laser annealing of transmon qubits, *Science Advances* (2022). [DOI: 10.1126/sciadv.abi6690](https://doi.org/10.1126/sciadv.abi6690)

T. D. Ladd et al, Quantum computers, *Nature* (2010). [DOI: 10.1038/nature08812](https://doi.org/10.1038/nature08812)

© 2022 Science X Network

Citation: Laser annealing transmon qubits for high-performance superconducting quantum processors (2022, May 19) retrieved 19 April 2024 from <https://phys.org/news/2022-05-laser-annealing-transmon-qubits-high-performance.html>

This document is subject to copyright. Apart from any fair dealing for the purpose of private study or research, no part may be reproduced without the written permission. The content is provided for information purposes only.