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Executive Summary

EXECUTIVE SUMMARY

Device: IBM Miami (ibm_miami)
Topology: Heavy-hex lattice
Total Qubits: 120
Operational Qubits: 120
Total CZ Edges: 216

CONNECTIVITY
  Interior qubits (4 neighbors): 77
  Edge qubits (3 neighbors): 38
  Corner qubits (2 neighbors): 5

COHERENCE TIMES
  T1: 312.3 +/- 111.6 us (range: 16.0 - 567.7 us)
  T2: 271.2 +/- 98.1 us (range: 34.4 - 574.2 us)
  T2/T1 ratio: 0.87 (ideal limit: 2.0)

GATE ERRORS
  Single-qubit (ID): 0.030% mean (0.022% median)
  Two-qubit (CZ): 0.70% mean (0.29% median)
  CZ gate length: 164 +/- 68 ns

READOUT
  Assignment error: 2.41% mean
  P(0|1) [false negative]: 3.28%
  P(1|0) [false positive]: 1.68%

KEY OBSERVATIONS
  - CZ error distribution is highly right-skewed (mean >> median)
  - 29 CZ edges are outliers (>0.007)
  - Worst CZ error: 17.3% (qubits 6-7)
  - 3 qubits violate T2 <= 2*T1 physical limit (measurement artifact or pulse errors)

Device Overview

IBM Miami is a 120-qubit superconducting quantum processor based on IBM's heavy-hex lattice topology. Each qubit is a transmon - an anharmonic oscillator formed by a Josephson junction shunted by a capacitor. The device operates at millikelvin temperatures (~15 mK) in a dilution refrigerator to minimize thermal excitations.

The heavy-hex topology arranges qubits in a pattern where most interior qubits have 4 nearest neighbors, while boundary qubits have 2-3 neighbors. This geometry is optimized for error correction codes while maintaining high-fidelity two-qubit gates.

Parameter Definitions (1/6)

Qubit Index
Integer identifier (0-119) for each physical qubit on the chip. The numbering follows the chip's spatial layout in the heavy-hex lattice topology.

T1 Relaxation Time (Energy Decay)
T1 characterizes the timescale for energy relaxation from the excited state $|1\rangle$ to the ground state $|0\rangle$. This is analogous to the longitudinal relaxation time in NMR.

Physical mechanism: The qubit couples to its electromagnetic environment (substrate defects, quasiparticles, radiation), causing spontaneous emission. The decay follows:

$$P_1(t) = P_1(0) \times \exp(-t/T1)$$

Longer T1 allows more gate operations before decoherence. Values >300 μs are considered excellent for superconducting qubits. Low T1 often indicates material defects or spurious coupling to lossy modes.

T2 Dephasing Time (Phase Coherence)
T2 characterizes the timescale for loss of phase coherence in a superposition state. For a state $|\psi\rangle = (|0\rangle + |1\rangle)/\sqrt{2}$, the off-diagonal density matrix elements decay as $\exp(-t/T2)$.

Physical mechanisms:
- T1 processes (energy decay also causes dephasing)
- Pure dephasing from low-frequency noise (flux noise, charge noise)

Fundamental limit: $T2 \leq 2 \times T1$ (from Bloch equations). T2 approaching $2 \times T1$ indicates T1-limited dephasing with minimal pure dephasing - a sign of a well-isolated qubit.

T2 is typically measured via Ramsey or Hahn echo sequences. Values reported here are likely T2* (Ramsey) or T2 echo, depending on IBM's calibration protocol.

Parameter Definitions (2/6)

Readout Assignment Error
The probability of incorrectly assigning the qubit state after measurement. This is the average of the two types of misclassification:

$$\varepsilon_{readout} = (P(0|1) + P(1|0)) / 2$$

Modern superconducting qubit readout uses dispersive measurement: the qubit state shifts the resonant frequency of a coupled readout resonator. A microwave pulse probes this resonator, and the reflected/transmitted signal is amplified and digitized.

Errors arise from:
- Finite signal-to-noise ratio in the measurement chain
- T1 decay during measurement (state flip before readout completes)
- Readout resonator thermal population
- Imperfect state discrimination thresholds

P(0|1) - False Negative Rate
Probability of measuring |0⟩ when the qubit was prepared in |1⟩. This is primarily caused by T1 decay during the measurement process.

If the readout duration is τ_{read} and T1 is the relaxation time:

$$P(0|1) \approx 1 - \exp(-\tau_{read} / T1)$$

High P(0|1) often correlates with low T1 or long readout pulses.

P(1|0) - False Positive Rate
Probability of measuring |1⟩ when the qubit was prepared in |0⟩. This can arise from:
- Thermal excitation of the qubit
- Measurement-induced excitation (QND violation)
- Readout resonator thermal population creating spurious signals
- Discrimination threshold errors

This error is typically smaller than P(0|1) since there's no T1 decay channel from |0⟩ to |1⟩ at millikelvin temperatures.

Parameter Definitions (3/6)

Readout Pulse Duration
The duration of the microwave pulse used to probe the readout resonator. Longer pulses provide better signal-to-noise (more photons) but increase the window for T1 decay.

Typical values: 500-3000 ns. The optimal length balances SNR against T1 decay.
IBM Miami uses 2400 ns uniformly across all qubits.

Identity Gate Error
Error rate of the identity (idle) operation over one gate cycle. This benchmarks decoherence during the time a qubit waits while other qubits are being operated on.

Measured via randomized benchmarking (RB) or similar protocols. The identity gate error sets a floor for all single-qubit operations since any gate includes at least this much decoherence.

$\text{ID error} \approx (\text{gate\_time} / T1 + \text{gate\_time} / T2) / 2$ for ideal gates.

Single-Qubit Gate Duration
Time to execute a single-qubit gate (e.g., X, Y, √X). For transmon qubits, these are microwave pulses at the qubit transition frequency.

Typical values: 20-50 ns. Shorter gates reduce decoherence during operations but require higher drive power (risking leakage to non-computational states).

IBM Miami uses 32 ns gates, which is relatively fast.

Parameter Definitions (4/6)

RX Gate Error (X-rotation)
Error rate for arbitrary rotations around the X-axis of the Bloch sphere. Measured via randomized benchmarking.

Physical implementation: A resonant microwave pulse with controlled amplitude and duration. Errors arise from:
- Pulse calibration imperfections (amplitude, frequency, phase)
- Decoherence during the gate
- Leakage to higher transmon levels
- Crosstalk from neighboring qubits

RZ Gate Error (Z-rotation)
Error rate for rotations around the Z-axis. In IBM's implementation, RZ gates are "virtual" - implemented by adjusting the phase of subsequent pulses rather than applying a physical pulse.

Virtual RZ gates have essentially zero error (only software phase tracking), which is why this column shows 0 for all qubits. This is a standard technique in superconducting qubit control.

SX Gate Error ($\sqrt{X}$ gate)
Error rate for the square-root of X gate, which performs a $\pi/2$ rotation around X. This is one of IBM's native gate set elements (along with RZ and CZ/ECR).

SX followed by SX equals X. Using SX as a native gate allows efficient decomposition of arbitrary single-qubit rotations.

X Gate Error (Bit Flip)
Error rate for the Pauli-X gate (π rotation around X), equivalent to a classical NOT operation: $|0\rangle \leftrightarrow |1\rangle$.

Typically X = SX × SX, so X error ≈ 2 × SX error (approximately, neglecting correlations).

Parameter Definitions (5/6)

CZ (Controlled-Z) Gate Error
Error rate for the two-qubit controlled-Z gate between connected qubit pairs.
CZ applies a π phase to the $|11\rangle$ state: $CZ|11\rangle = -|11\rangle$.

Format: "neighbor1:error1;neighbor2:error2;..." listing all connected qubits and their respective CZ error rates.

Physical implementation varies (cross-resonance, tunable coupler, etc.). Two-qubit gates are typically 10-100× noisier than single-qubit gates due to:
- Longer gate duration
- Coupling to additional decoherence channels
- Calibration sensitivity
- Crosstalk and spectator qubit errors

CZ errors are the dominant error source in most quantum algorithms.

CZ Gate Duration
Duration of the two-qubit CZ gate for each qubit pair.

Format mirrors CZ error: "neighbor1:duration1;neighbor2:duration2;..."

Typical values: 100-500 ns. Duration varies by qubit pair due to:
- Frequency detuning between qubits
- Coupling strength
- Required pulse shaping for leakage suppression

Longer gates generally have higher error rates due to increased decoherence.

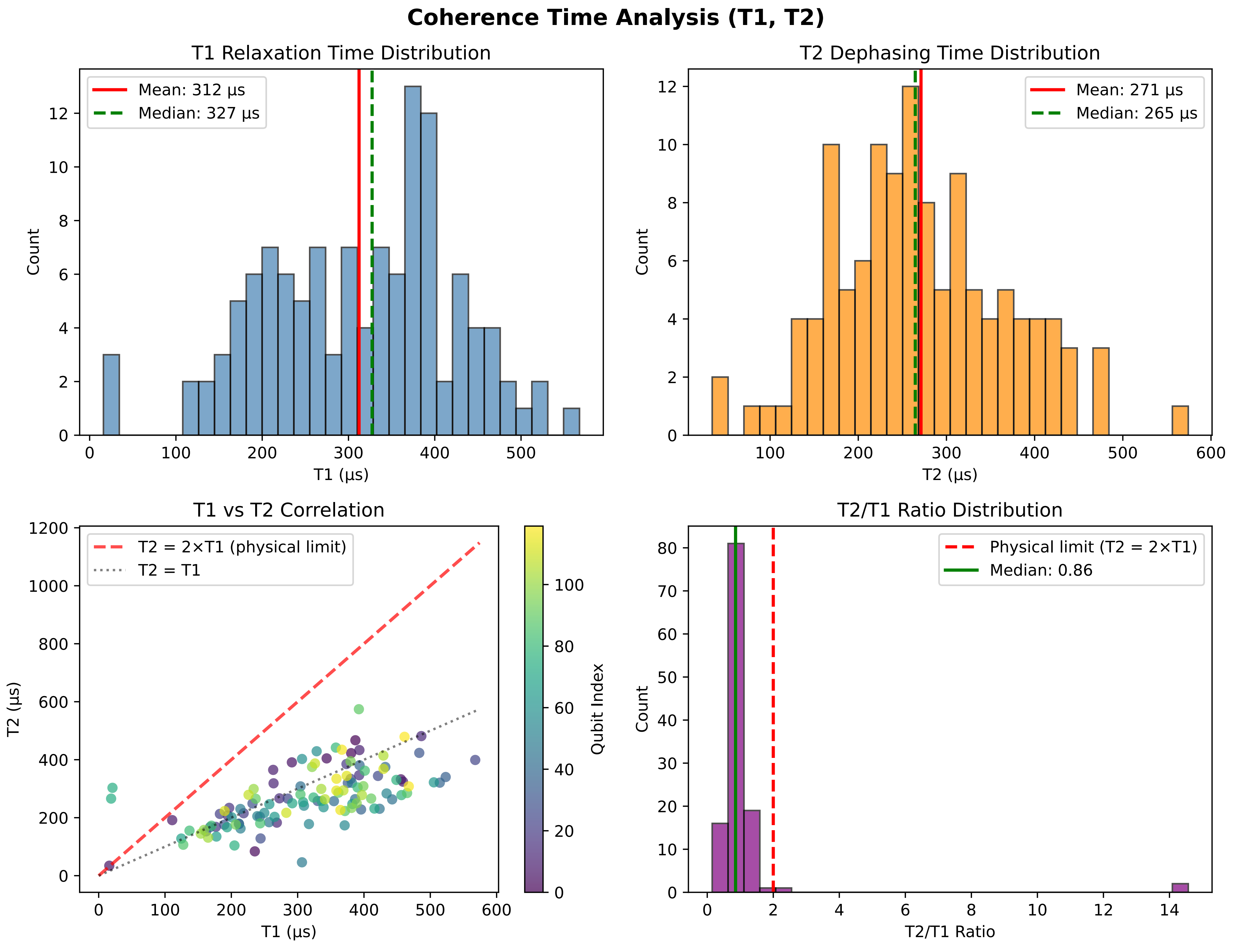
Parameter Definitions (6/6)

Measurement Error
Error rate for the measurement operation, typically equal to the readout assignment error. May include additional systematic effects from the measurement protocol.

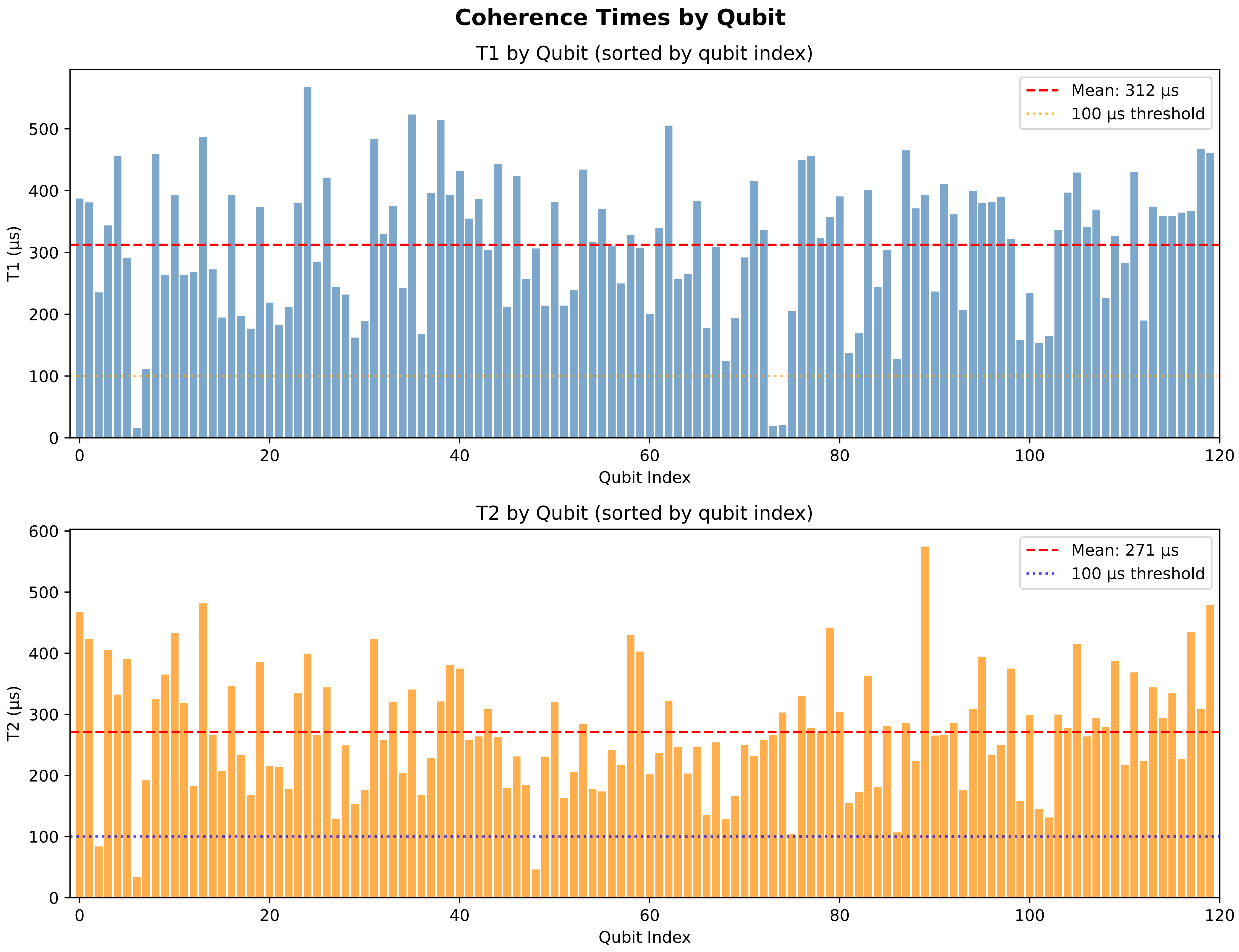
Note: MEASURE error equals Readout assignment error in this dataset.

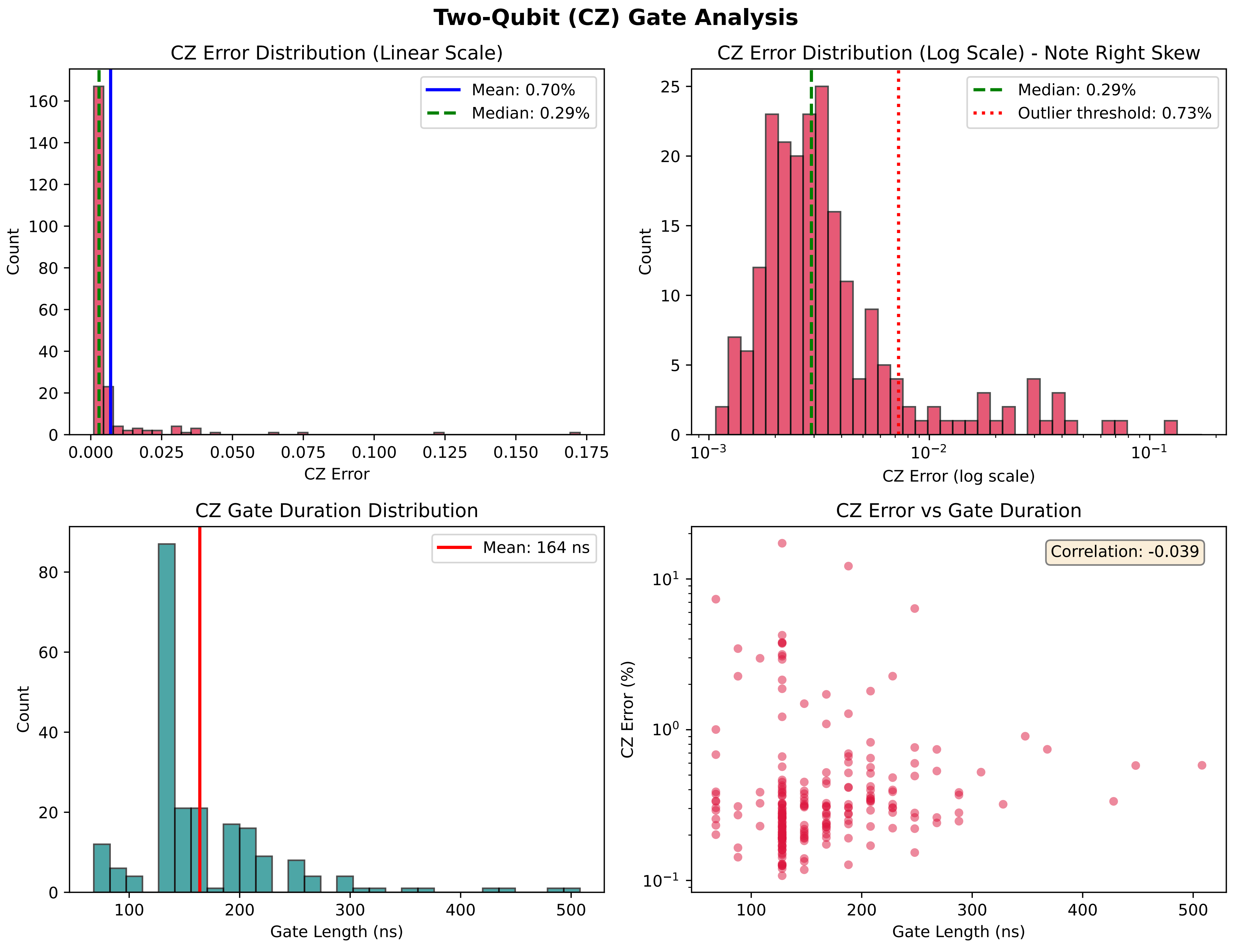
Operational Status
Whether the qubit passed calibration and is available for use. "Yes" indicates the qubit meets IBM's quality thresholds. Failed qubits would show "No" and should be avoided in circuit design.

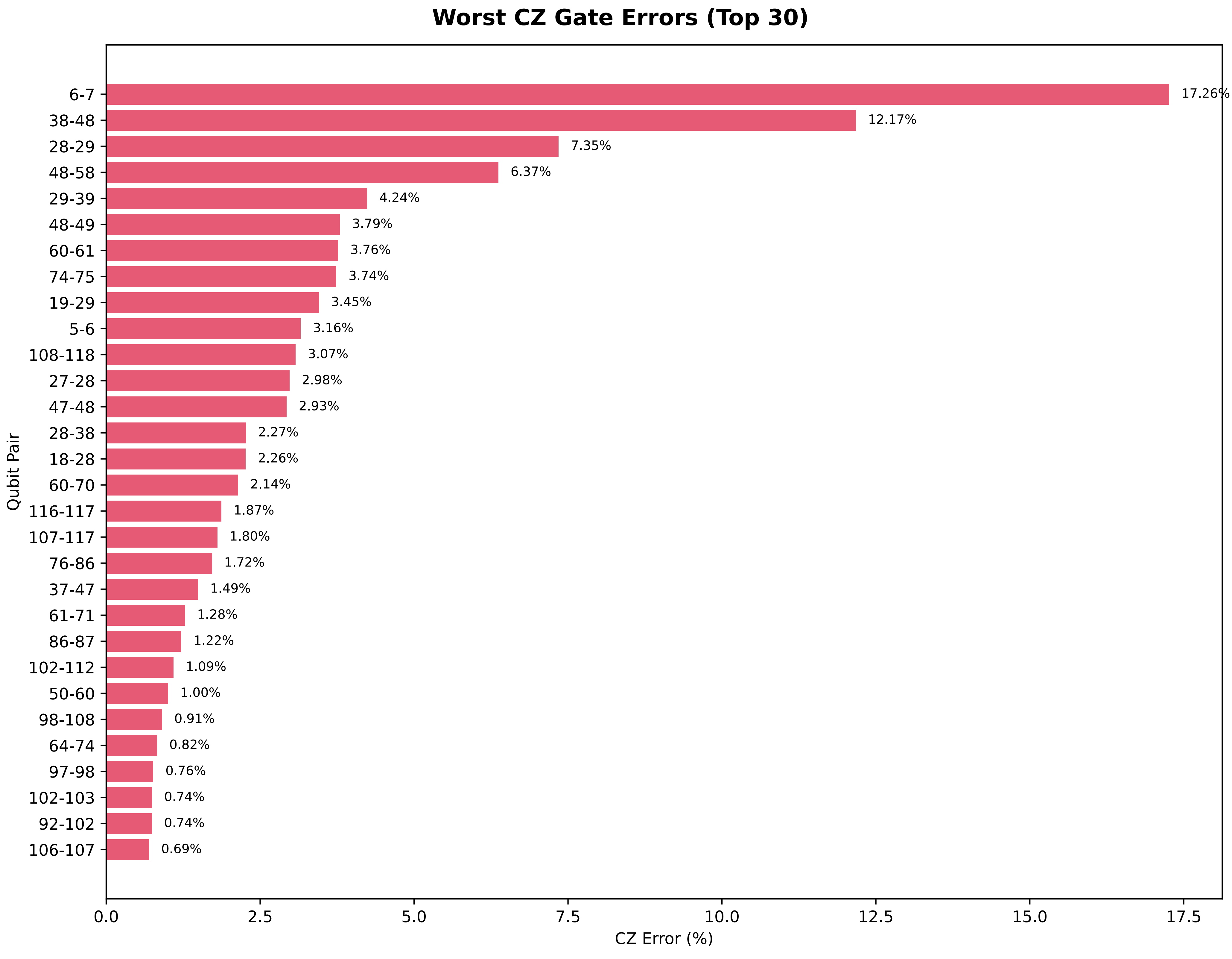
All 120 qubits are operational in this calibration snapshot.



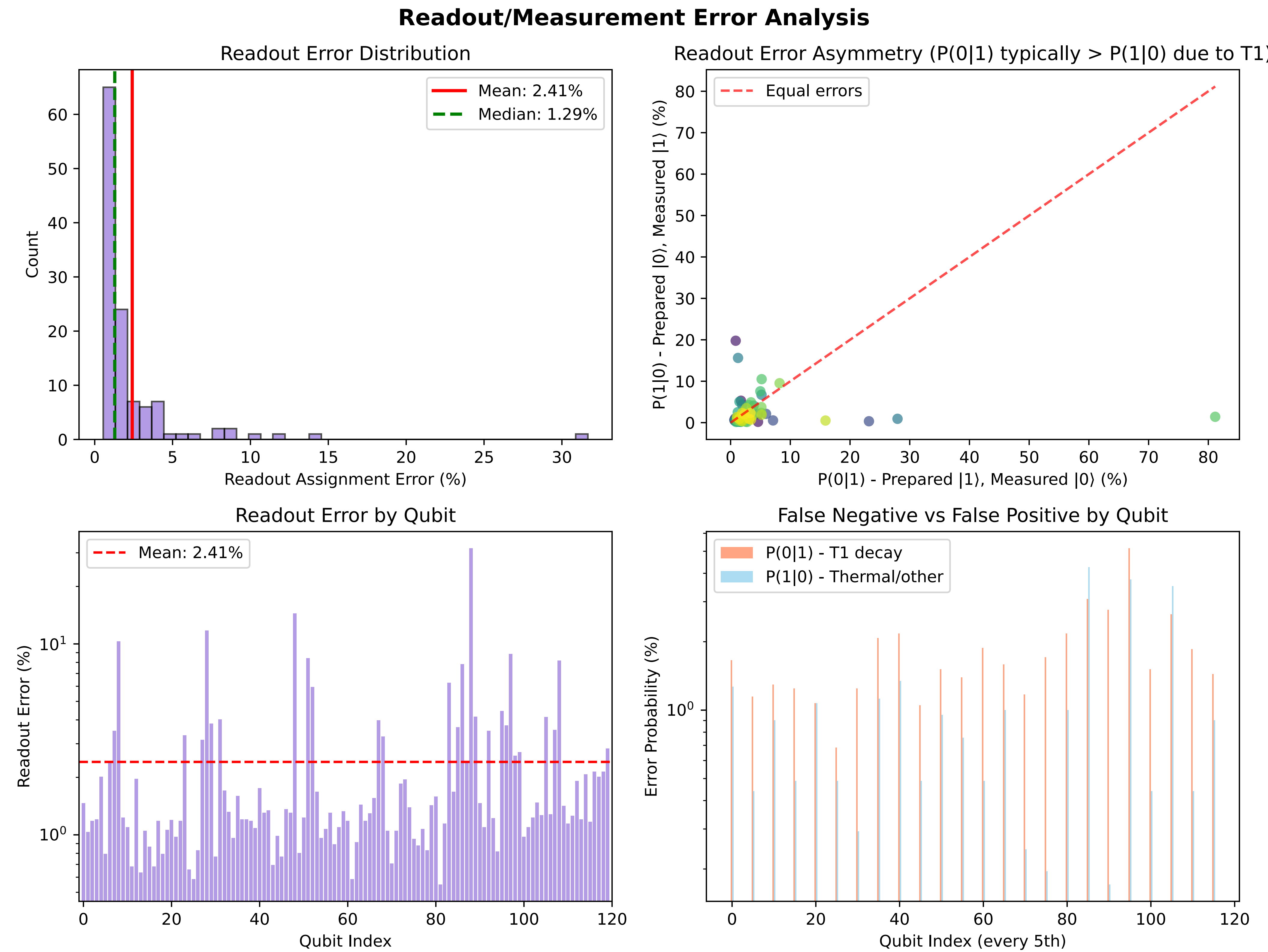
Coherence Time Analysis (T1, T2)
T1 Relaxation Time Distribution
Mean: 312 μs
Median: 327 μs
Count
T1 (μs)
T2 Dephasing Time Distribution
Mean: 271 μs
Median: 265 μs
Count
T2 (μs)
T1 vs T2 Correlation
T2 = 2×T1 (physical limit)
T2 = T1
T2 (μs)
T1 (μs)
Qubit Index
T2/T1 Ratio Distribution
Physical limit (T2 = 2×T1)
Median: 0.86
Count
T2/T1 Ratio


Coherence Times by Qubit
T1 by Qubit (sorted by qubit index)
Mean: 312 µs
100 µs threshold
T1 (µs)
Qubit Index
T2 by Qubit (sorted by qubit index)
Mean: 271 µs
100 µs threshold
T2 (µs)
Qubit Index


Two-Qubit (CZ) Gate Analysis
CZ Error Distribution (Linear Scale)
Mean: 0.70%
Median: 0.29%
Count
CZ Error
CZ Error Distribution (Log Scale) - Note Right Skew
Median: 0.29%
Outlier threshold: 0.73%
Count
CZ Error (log scale)
CZ Gate Duration Distribution
Mean: 164 ns
Count
Gate Length (ns)
CZ Error vs Gate Duration
Correlation: -0.039
CZ Error (%)
Gate Length (ns)



Worst CZ Gate Errors (Top 30)
6-7
38-48
28-29
48-58
29-39
48-49
60-61
74-75
19-29
5-6
108-118
27-28
47-48
28-38
18-28
60-70
116-117
107-117
76-86
37-47
61-71
86-87
102-112
50-60
98-108
64-74
97-98
102-103
92-102
106-107
17.26%
12.17%
7.35%
6.37%
4.24%
3.79%
3.76%
3.74%
3.45%
3.16%
3.07%
2.98%
2.93%
2.27%
2.26%
2.14%
1.87%
1.80%
1.72%
1.49%
1.28%
1.22%
1.09%
1.00%
0.91%
0.82%
0.76%
0.74%
0.74%
0.69%
Qubit Pair
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
CZ Error (%)

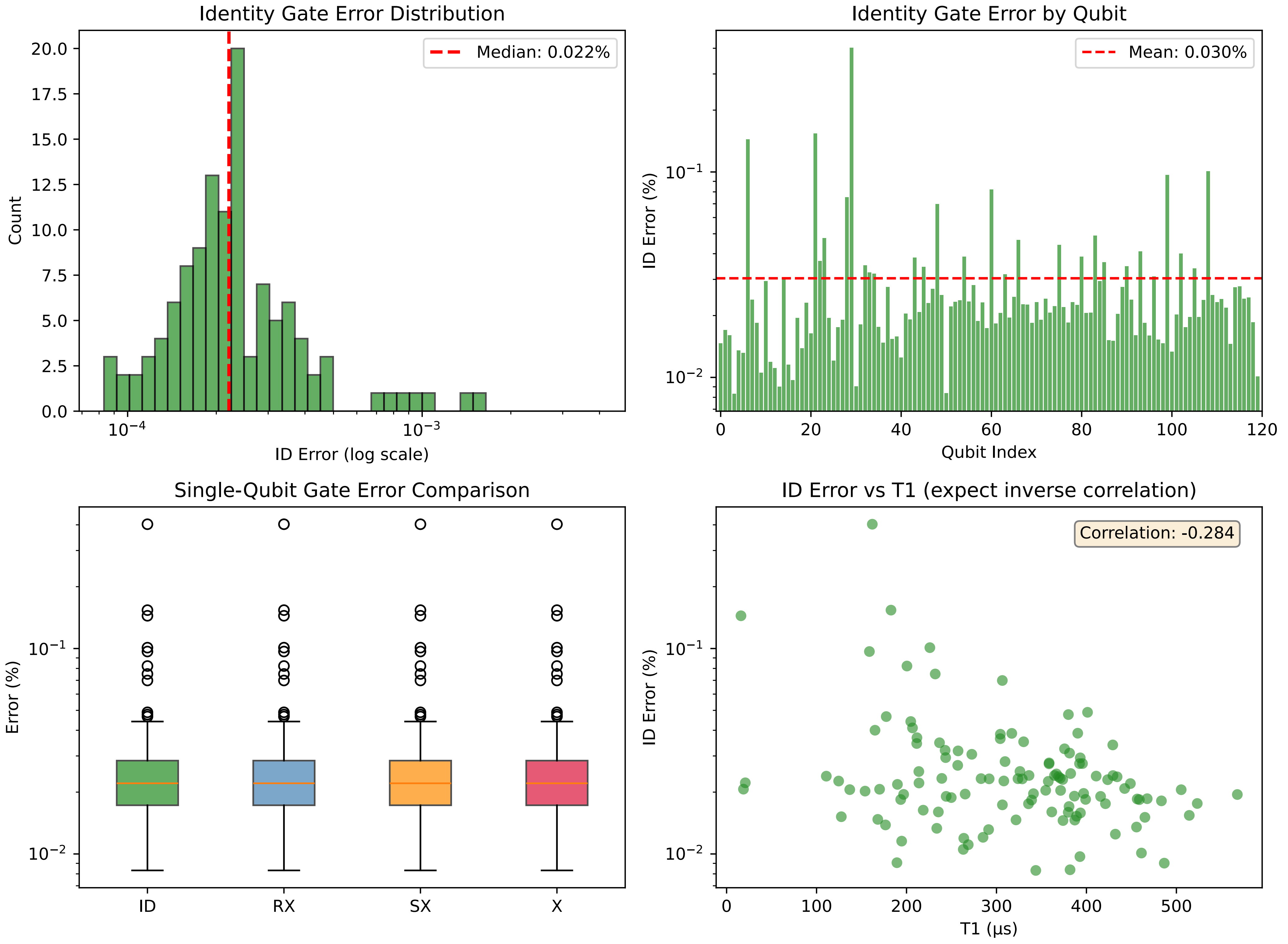


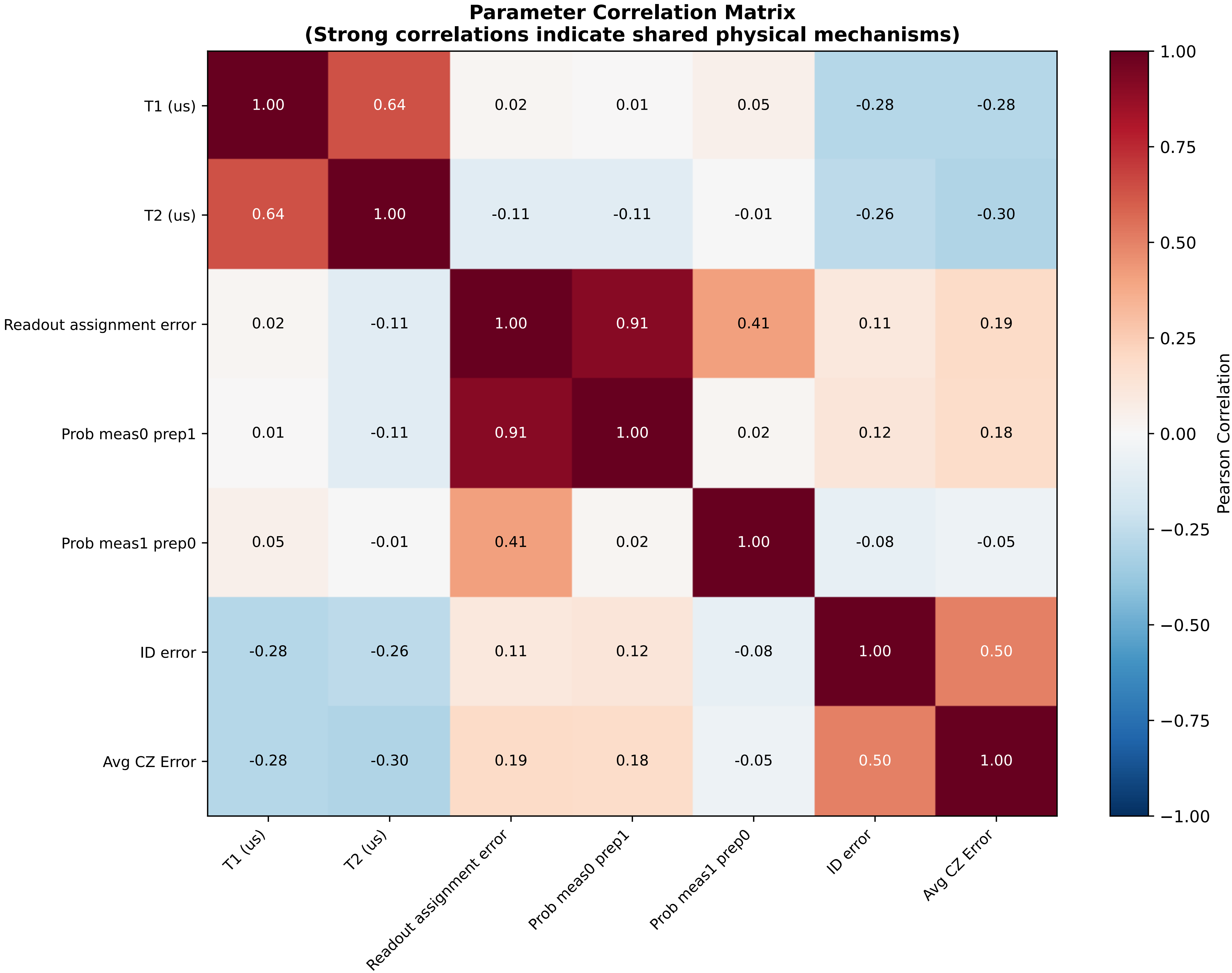
Readout/Measurement Error Analysis
Readout Error Distribution
Mean: 2.41%
Median: 1.29%
Count
Readout Assignment Error (%)
Readout Error Asymmetry (P(0|1) typically > P(1|0) due to T1)
Equal errors
P(1|0) - Prepared |0⟩, Measured |1⟩ (%)
P(0|1) - Prepared |1⟩, Measured |0⟩ (%)
Readout Error by Qubit
Mean: 2.41%
Readout Error (%)
Qubit Index
False Negative vs False Positive by Qubit
P(0|1) - T1 decay
P(1|0) - Thermal/other
Error Probability (%)
Qubit Index (every 5th)

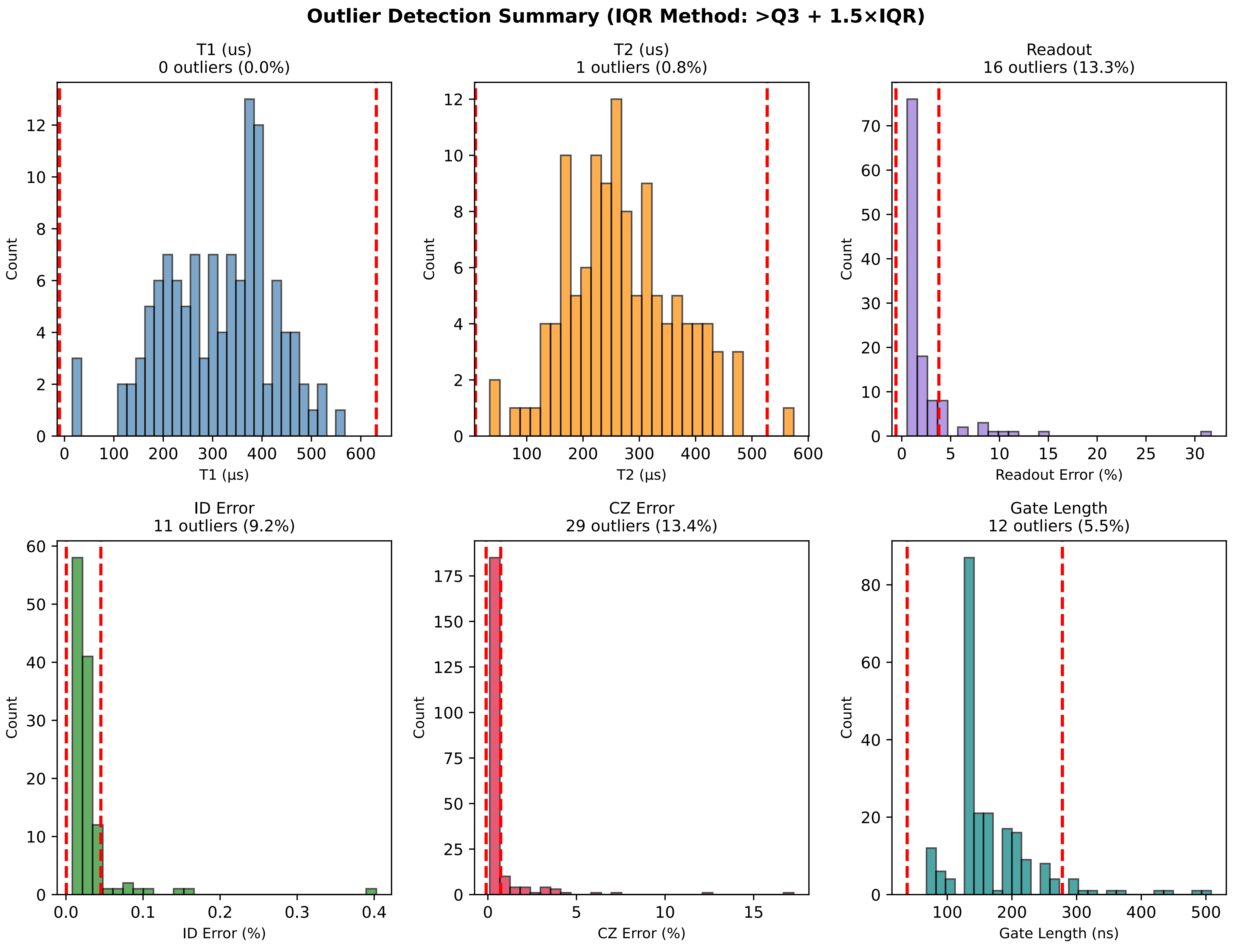
Top 20 Worst Readout Qubits
(Note correlation between high P(0|1) and T1)

Qubit	Assignment Error	P(0|1)	P(1|0)	T1 (μs)
88	31.67%	81.15%	1.42%	371.3
48	14.44%	27.95%	0.93%	306.5
28	11.76%	23.17%	0.34%	231.9
8	10.31%	0.85%	19.78%	458.8
97	8.86%	8.20%	9.52%	389.0
51	8.44%	1.25%	15.62%	213.9
108	8.20%	15.89%	0.51%	226.0
86	7.85%	5.20%	10.50%	127.5
83	6.27%	4.98%	7.57%	401.2
52	5.96%	5.18%	6.74%	239.2
95	4.46%	5.15%	3.76%	379.8
89	4.16%	3.42%	4.91%	392.3
105	4.15%	2.64%	3.52%	429.3
31	4.03%	5.93%	2.12%	483.4
67	3.98%	3.86%	4.10%	308.2
29	3.82%	7.10%	0.54%	162.0
96	3.75%	5.13%	2.37%	381.3
85	3.66%	3.08%	4.25%	304.2
107	3.55%	5.20%	1.90%	369.0
7	3.52%	1.73%	5.30%	110.9

Single-Qubit Gate Error Analysis




Parameter Correlation Matrix
(Strong correlations indicate shared physical mechanisms)
T1 (us)
T2 (us)
Readout assignment error
Prob meas0 prep1
Prob meas1 prep0
ID error
Avg CZ Error
1.00 0.64 0.02 0.01 0.05 -0.28 -0.28
0.64 1.00 -0.11 -0.11 -0.01 -0.26 -0.30
0.02 -0.11 1.00 0.91 0.41 0.11 0.19
0.01 -0.11 0.91 1.00 0.02 0.12 0.18
0.05 -0.01 0.41 0.02 1.00 -0.08 -0.05
-0.28 -0.26 0.11 0.12 -0.08 1.00 0.50
-0.28 -0.30 0.19 0.18 -0.05 0.50 1.00
Pearson Correlation
1.00
0.75
0.50
0.25
0.00
−0.25
−0.50
−0.75
−1.00



Outlier Detection Summary (IQR Method: >Q3 + 1.5×IQR)
T1 (us)
0 outliers (0.0%)
T2 (us)
1 outliers (0.8%)
Readout
16 outliers (13.3%)
ID Error
11 outliers (9.2%)
CZ Error
29 outliers (13.4%)
Gate Length
12 outliers (5.5%)
Count
T1 (μs)
T2 (μs)
Readout Error (%)
ID Error (%)
CZ Error (%)
Gate Length (ns)

15 WORST Qubits
(Highest composite error score)

Qubit	T1 (μs)	T2 (μs)	Readout	ID Err	CZ Err
6	16	34	2.39%	0.144%	10.21%
48	307	46	14.44%	0.070%	6.32%
29	162	153	3.82%	0.403%	5.01%
88	371	223	31.67%	0.020%	0.41%
28	232	249	11.76%	0.075%	3.71%
73	19	266	1.95%	0.021%	0.28%
74	21	303	1.39%	0.022%	1.29%
7	111	192	3.52%	0.024%	5.94%
108	226	279	8.20%	0.101%	1.14%
86	128	107	7.85%	0.015%	0.95%
21	183	213	0.98%	0.154%	0.36%
60	200	201	1.18%	0.082%	2.30%
99	159	158	2.71%	0.097%	0.41%
75	205	104	0.95%	0.044%	1.18%
51	214	163	8.44%	0.022%	0.23%

15 BEST Qubits
(Lowest composite error score)

Qubit	T1 (μs)	T2 (μs)	Readout	ID Err	CZ Err
13	487	481	0.63%	0.009%	0.21%
16	393	347	0.68%	0.010%	0.19%
3	344	405	1.21%	0.008%	0.18%
0	387	467	1.46%	0.015%	0.12%
1	381	423	1.04%	0.017%	0.16%
24	568	399	0.66%	0.019%	0.31%
26	421	344	0.83%	0.018%	0.19%
40	432	375	1.76%	0.012%	0.16%
11	264	319	0.68%	0.012%	0.22%
9	263	365	1.23%	0.011%	0.23%
59	307	402	1.33%	0.017%	0.19%
10	393	433	1.10%	0.029%	0.12%
119	461	479	2.83%	0.010%	0.25%
62	505	322	0.92%	0.021%	0.26%
113	374	344	1.21%	0.015%	0.32%

Comprehensive Statistical Summary
(Outliers detected via IQR method)

Parameter	Count	Mean	Std	Median	Min	Max	Outliers
T1 (µs)	120	312.2645	111.1582	327.3846	15.9922	567.7464	0
T2 (µs)	120	271.1514	97.6975	264.6408	34.3711	574.2115	1
Readout Error (%)	120	2.4098	3.5237	1.2878	0.5493	31.6650	16
P(0|1) (%)	120	3.2762	7.9575	1.7212	0.6348	81.1523	15
P(1|0) (%)	120	1.6774	2.7148	0.9033	0.1709	19.7754	16
ID Error (%)	120	0.0304	0.0406	0.0221	0.0083	0.4028	11
CZ Error (%)	216	0.7003	1.6642	0.2917	0.1075	17.2622	29
Gate Length (ns)	218	163.9266	68.1380	138.0000	68.0000	508.0000	12