

Quantumograph Theory Predictions

I. Predictions for qubit platforms (QPU, annealer, gate model)

- 1. Single measurable energy scale $T_c = Jz/k_B$** — the central operative formula: J is the average two-qubit coupling, z is the average vertex degree; all main predictions are parameterized by this scale.
 - 2. Heat-capacity peak / crossover at $T \approx T_c$** — a measurable manifestation of the transition between the “correlated” and “disconnected” regimes. Protocols for temperature scans and criteria for identifying the peak are provided (steps and expected precision).
 - 3. QPU error-rate crossover at $T \sim T_c$** — a rapid change (drop/increase) of logical and physical error rates is expected; it is proposed to measure this via RB / short logical circuits as a function of temperature.
 - 4. Correlation-length collapse $\Psi(r,T)$** — for $T > T_c$ correlations decay exponentially; for $T < T_c$ long-lived clustered correlations appear. A method is proposed: prepare $|+\rangle$, wait, and measure pairwise correlators.
 - 5. DOS-driven spectral shifts in two-qubit spectroscopy** — corrections to the low-mode density of states produce measurable shifts in the spectrum that can be extracted by measuring J_{ij} and the Laplacian spectrum.
 - 6. Graph automorphisms \rightarrow testable “symmetries” / spontaneous symmetry breaking** — the prediction that the automorphism group determines a set of possible gauge groups; experimentally this is probed via dependence of observables on topology and tests on randomized topology. (Control: if the effect persists after topology randomization \rightarrow the topological hypothesis is falsified).
 - 7. Numerical examples / scale estimates for motifs:** in Villain/Josephson approximations example frequencies/energies are given: *chimera_like_5x5* ≈ 55 GHz; *square_grid_20x20* ≈ 227 GHz; *random-regular_degree-4* ≈ 43 THz. These numbers serve as working design targets.
 - 8. Practical limits for annealer topologies** — chain embedding, Chimera sparsity ($z \approx 6$) and denser Pegasus ($z \approx 15$) affect T_c : e.g., with $J \approx 20$ MHz and $z \approx 6$ one expects $T_c \approx 30$ mK; Pegasus can raise T_c to ≈ 75 mK. Recommendations: avoid/compensate chain embeddings and use topology-aware embedding.
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II. Microwave/ dielectric predictions

- 1. Resonant microwave anomalies (dip/minimum in absorption) at $\omega \approx \omega_{\text{char}}$** — collective “graph-phonon” modes produce characteristic frequencies; a dip structure in $\tan\delta(\omega)$ is predicted for $T < T_c$.
- 2. Material-specific frequencies and temperature coefficients** — a table gives example values (PMN-PT, MoS₂, BGO, PVDF–TiO₂) and numerical guides (GHz values at $T = 0.5T_c$ and sensitivity $\Delta/\Delta T$).

3. Falsification threshold by frequency — the theory is considered falsified if, under prepared conditions and within experimental precision, the characteristic frequency shift $\omega \backslash \omega_a \omega$ at $T \rightarrow 0.5T_c$ is smaller than **10 kHz** (falsification criterion).

4. Threshold for $\Delta(\tan\delta)$ — expected topological microwave anomalies are of order $\Delta(\tan\delta) \geq 10^{-4}$; the text gives SNR/noise levels and temperature-resolution requirements down to $\lesssim 0.01$ mK for some materials.

5. Experimental protocol — cryo-stabilization, shielding, S21 sweeps from 0.1–10 GHz, extraction of $\tan\delta$, and requirements for temperature sensors and SNR.

III. Causality / retrocausality (two-boundary formulation) — testable signatures

1. Shift in conditional probability $\Delta P(a|b) \neq 0$ — the primary operational sign of retrocausal contribution: a significant deviation of empirical $P(a|b)$ from standard QM predictions under post-selection. Experimentally: protocols A (Bell-type delayed-choice), B (rare strong post-selection), and C (multi-qubit QPU test) are proposed.

2. Anomalies in weak values (weak-value anomalies) — weak-value distributions may show heavy tails / shifted centers; look for deviations in rare-event statistics.

3. Differences in higher-order correlators — two-point correlators typically match QM at leading order; deviations are expected to be more pronounced in three- and multi-point correlators and in joint distributions of local observables.

4. Scaling with rarity of post-selection — if the effect increases as the post-selection probability p_{post} decreases, this is an expected signature of two-boundary contributions (tradeoff: signal boost vs. statistics).

5. Topological dependence of retro-shift — the magnitude of ΔP depends on spectral dimension and z : higher connectivity or lower spectral dimension can enhance the effect; formulae and topology choices to maximize the signal are given.

6. Required statistics for detection — explicit numerical estimates: to detect a $\pm 1\%$ signal one needs $M \gtrsim 62,500$ trials; for $\pm 0.1\% \rightarrow M \gtrsim 6,250,000$; for 10^{-4} level \rightarrow hundreds of millions (example: $M \gtrsim 625,000,000$). These figures are derived and discussed step-by-step.

7. Falsification / control criteria — required checks: no-signalling (marginals without post-selection must match QM), physical RNG for delayed-choice, bootstrap to quantify post-selection bias, and replication across platforms (optical, superconducting, QPU).

IV. Practical thresholds, checklists and “decisive” experiment behavior

1. Topological control — always compare to a control: a randomized topology with the same degree histogram. If the effect persists on the randomized topology, the topological explanation is falsified.

2. Reporting uncertainties — in the explicit formula for $\Delta T_c/T_c$ provide separate statistical and systematic error bars; if systematics dominate, give a conservative interval.

3. Practical acquisition recommendations — for gate-model: shots ≈ 1024 , gauge randomizations ≈ 10 , temperature repeats ≈ 10 ; for annealers: samples per embedding $\approx 10,000$, gauge transforms ≈ 20 . These parameters yield target statistical errors of $\sim 1\text{--}2\%$ per measurement point.

4. Summary falsification criteria:

- microwave frequency shift at $T \rightarrow 0.5T_c < 10$ kHz \rightarrow theory falsified;
- topological effect remains on randomized topology \rightarrow topological explanation falsified;
- after all mandatory control tests (no-signalling, etc.), deviations remain significant \rightarrow the retrocausal hypothesis becomes a subject of increased support.

V. Additional (broader) predictions relevant to experiments

- **CHSH / Bell:** the construction indicates that achieving $S \approx 2.76$ requires “sub-atomic” connectivity (very high graph connectivity); estimated relations and corollaries about graph diameter / information transfer time are provided.
- **Emergent constants and cosmological links:** dimensionless constants like α are, in principle, computable from the graph spectral functionals; practical tests require large-scale numerical scans of. This is a longer-term prediction but comes with a clear roadmap for verification.