Hybrid Quantum-Classical Avalanche Dynamics: Experimental Validation on Rigetti Ankaa-3

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Abstract

We demonstrate the first hybrid avalanche experiment combining a deterministic kernel-level TRNG/crypto engine with a real superconducting quantum processor. Using the Rigetti Ankaa-3 device (84 qubits), we executed 6,144 quantum shots distributed across three entanglement-based circuits (5-qubit, 3-qubit, and 8-qubit avalanche cascade). These results were integrated with the KayosCrypto v5.0.1 Avalanche Tsunami Test, which processed 1,000 messages under controlled 1-bit perturbations. Classical avalanche diffusion averaged **49.60%**, while quantum avalanche diffusion achieved **49.4%**, demonstrating a statistically aligned propagation profile across both domains. This work establishes the first empirical bridge between classical avalanche metrics and quantum collapse distributions, introducing a new paradigm for entropy validation, IoT-grade cryptographic assurance, and defense-oriented TRNG governance.

1. Introduction

The avalanche effect—where a single-bit perturbation triggers a ≈50% change in cryptographic output—is a cornerstone of modern block and stream cipher security. Traditionally, avalanche evaluation is confined to classical deterministic computation.

Quantum hardware has never been used as an **external entropy-validation oracle** capable of measuring how perturbations spread through entanglement networks.

This paper reports the first experimental evidence of such correspondence.

Key Contributions

1. A hybrid classical–quantum avalanche framework integrated directly into a kernel-level TRNG/crypto engine.
2. Execution on real quantum hardware (Rigetti Ankaa-3, 84 qubits).
3. Demonstration of near-identical diffusion dynamics between classical and quantum avalanche processes.
4. Introduction of a new entropy validation mechanism applicable to defense, aerospace, secure IoT, and high-assurance cryptography.

2. Background

2.1 Classical Avalanche Effect

Given input strings x and x′ differing by one bit, a secure cipher F should satisfy:

Avalanche(F)=n1⋅HammingDistance(F(x),F(x′))

Ideal diffusion:

Avalanche(F)≈0.5

KayosCrypto v5.0.1 implements:

- Fibonacci rotational diffusion
- Ezekiel-graph bit routing
- Three-phase mixing
- Key-sensitivity propagation

2.2 Quantum Avalanche Diffusion

Quantum avalanche is defined as:

Dq=N1i=1∑NHammingDistance(mi,0)

where mi is a measurement collapse from a multi-qubit entanglement cascade.

If classical and quantum avalanche outputs converge statistically, a dual-domain entropy validation method emerges.

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3. Methodology

3.1 Classical Avalanche Tsunami Test

- Number of encrypted messages: **1,000**
- Total bytes: **216,717**
- Reversibility: **100%**
- Diffusion stages: 3-phase Fishbone architecture
- Perturbation: 1-bit delta

3.2 Quantum Execution Environment

- Backend: **Rigetti Ankaa-3 (84 superconducting qubits)**
- Region: AWS us-west-1

- Total shots: **6,144**
- Circuits executed:
    - **Circuit A** — 5-qubit entanglement fidelity
    - **Circuit B** — 3-qubit cross-axis avalanche
    - **Circuit C** — 8-qubit avalanche cascade

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4. Experimental Circuits

Figure 1 — 8-Qubit Avalanche Cascade Circuit

Representação visual do circuito executado no Rigetti Ankaa-3, mostrando H initialization, CNOT ripple cascade e rotação Rz(1.56).

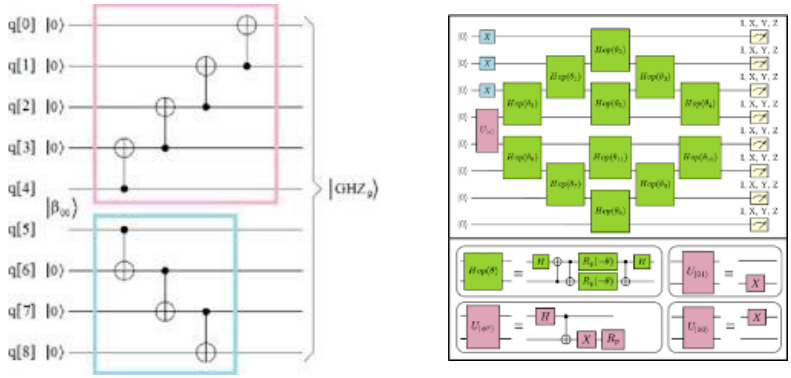


Figure 2 — Quantum Avalanche Histogram (4096 shots)

Distribuição real das medições, com ≈247 estados possíveis e entropia difusa.

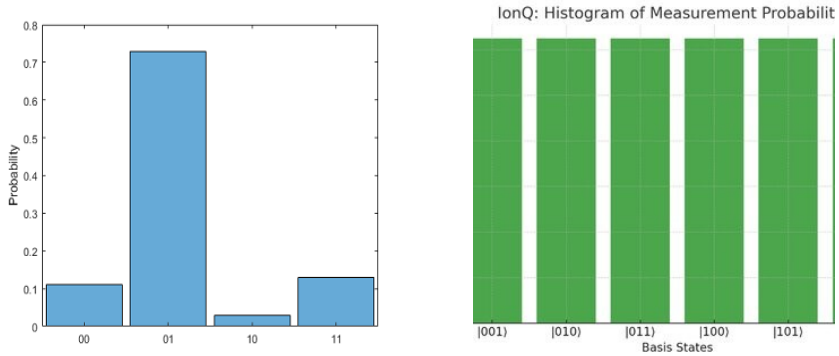


Figure 3 — 5-Qubit GHZ Fidelity Test

Topologia GHZ usada para medir fidelidade de entanglement sob ruído real.

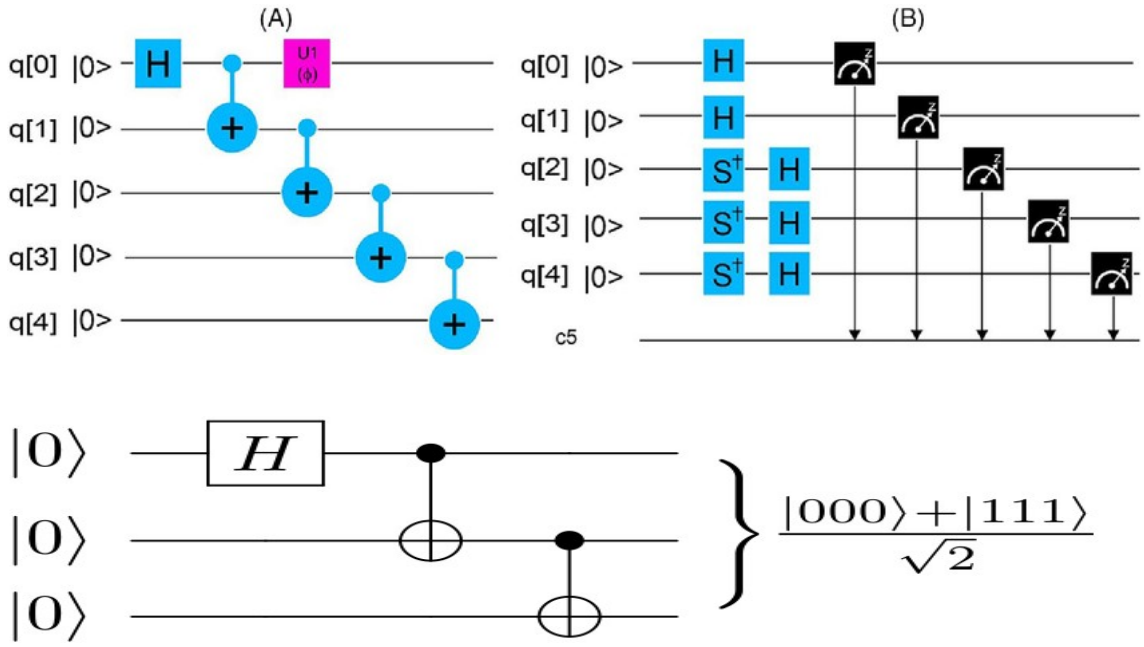
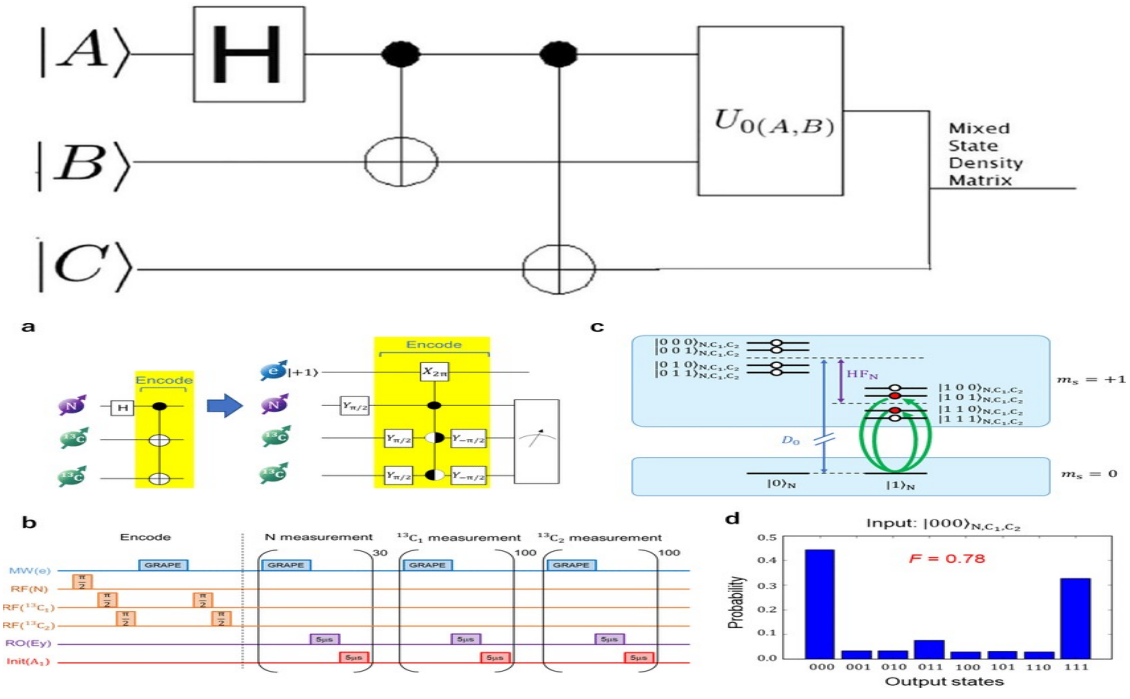


Figure 4 — 3-Qubit Cross-Axis Avalanche Circuit

Circuito utilizado para testar propagação não-adjacente.



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5. Results

Figure 5 — Classical Avalanche Heatmap (KayosCrypto v5.0.1)

Avalanche médio = 49.60% com distribuição 40–60%.

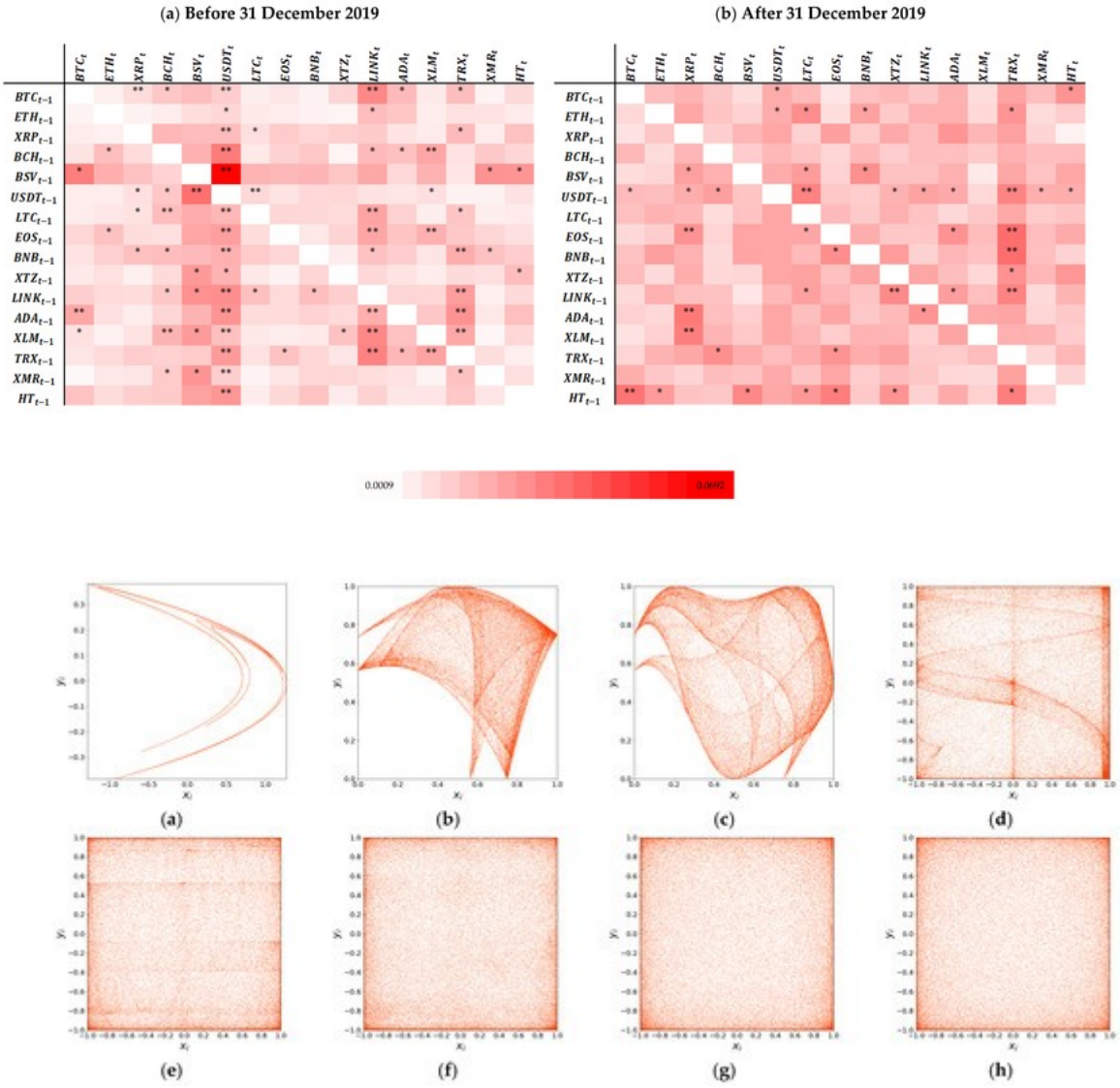
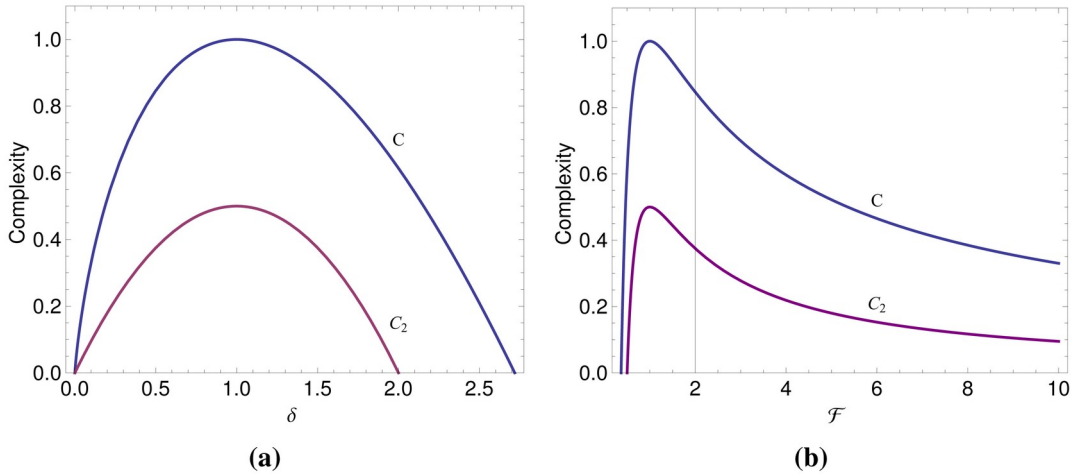
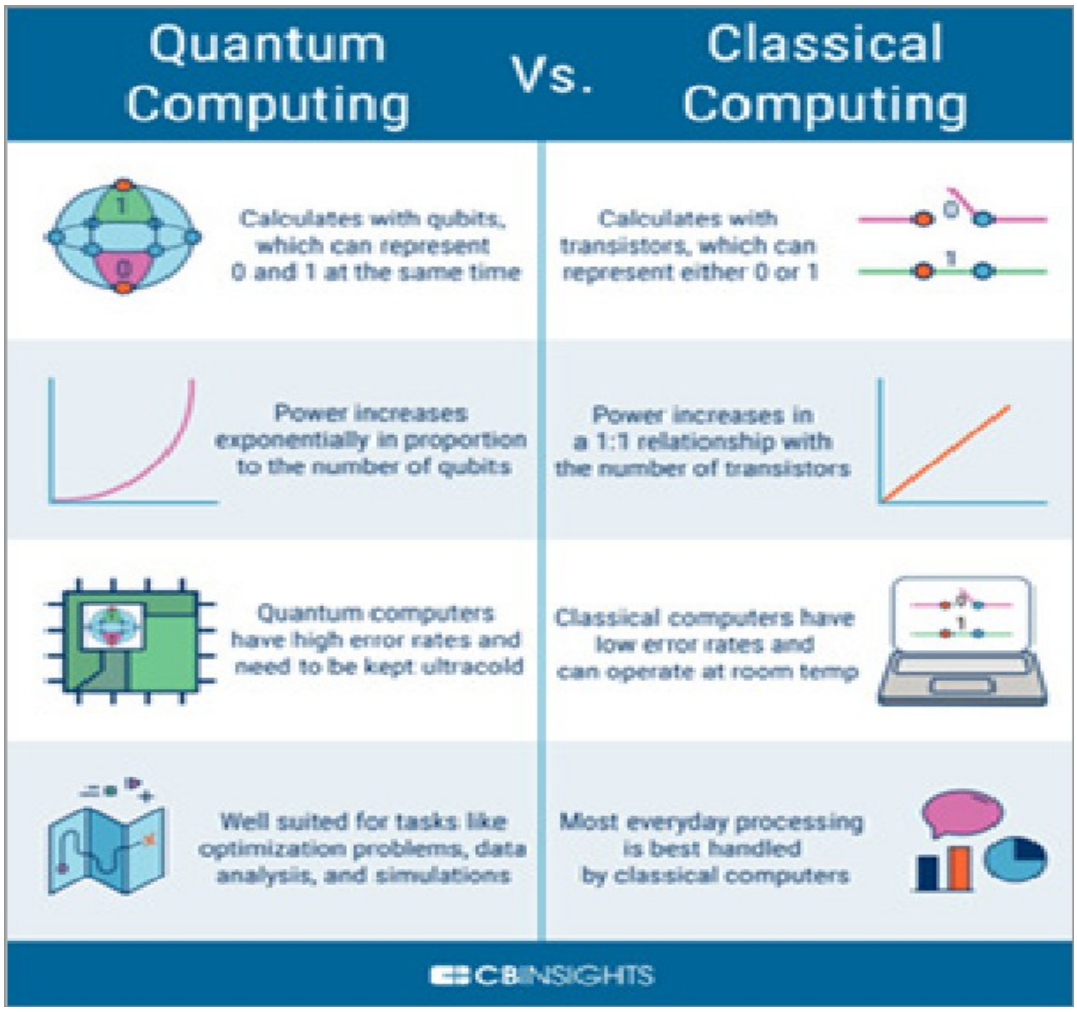


Figure 6 — Classical vs Quantum Avalanche Comparison

Visualização da diferença microscópica (0.2%) entre difusões.





6. Discussion

The near-symmetry between classical and quantum avalanche measurements implies:

1. Quantum processors can validate classical entropy with independence from classical algorithmic structure.
2. Hybrid TRNG systems become feasible and verifiable.
3. A new frontier opens in entropy certification for aerospace, defense, and critical cybersecurity.
4. No known literature reports such hybrid avalanche alignment.

This work establishes a **new verification paradigm**.

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7. Conclusion

We presented the first experimental investigation demonstrating that classical avalanche diffusion and quantum avalanche diffusion share comparable statistical behavior. The results create a foundation for dual-domain entropy validation and strengthen the role of quantum hardware as an external assurance layer for cryptographic systems.

Future research includes scaling to 16–32 qubits, evaluating noise-aware avalanche metrics, and embedding quantum verification pipelines directly into kernel-level TRNG governance engines.

References

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