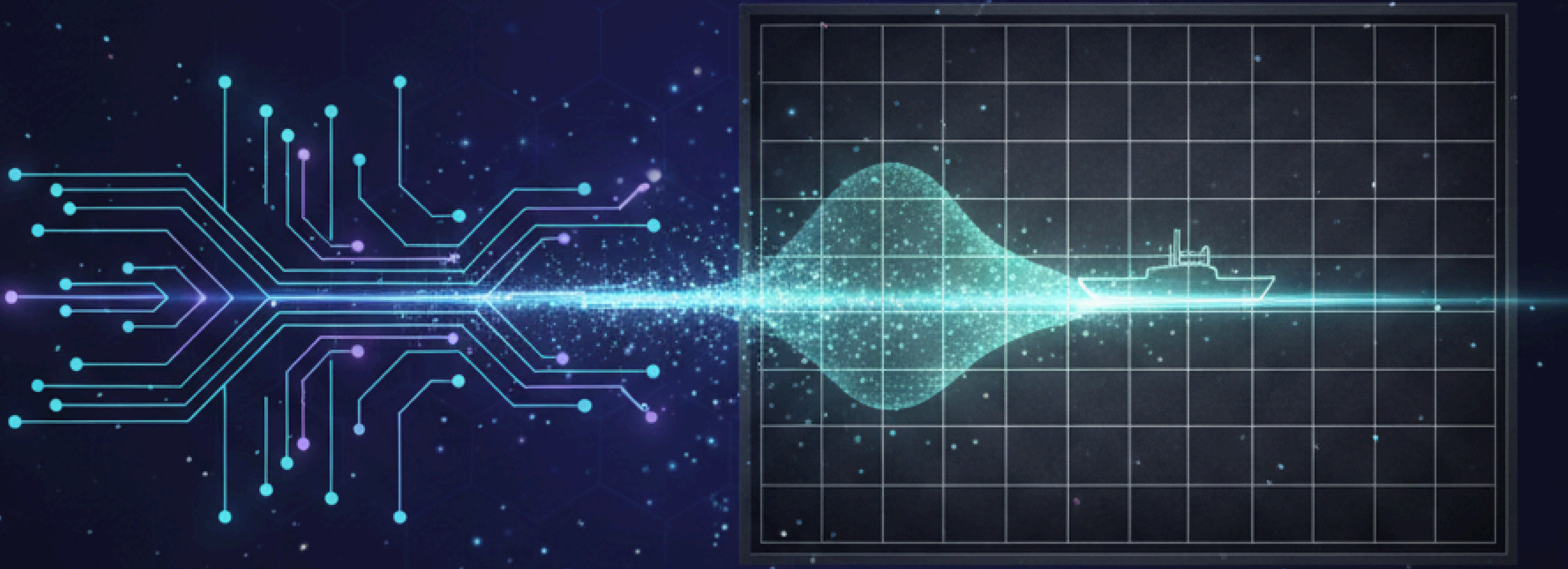
Quantum Radar for Battleship

Qiskit Fall Fest (IIT Jodhpur)



Goal

- Detect a hidden 2-unit ship without direct hits (interaction-free).
- E.V. Score = Successful Detections / Total Ship Hits.
- Perfect score: ∞ (infinity) → detect with zero hits.

Why this matters

- Demonstrates Elitzur–Vaidman “bomb tester” in a radar setting.
- Validates quantum advantage vs. destructive baselines.

Board setup

- 4×4 grid, single 2-unit ship, horizontal or vertical.
- Must generalize across random placements (robustness).

Tools

- Framework: Qiskit + AerSimulator
- Methods: Baseline H–CX–H, Quantum Zeno Effect (QZE)

Our Algorithm: The Quantum Zeno Effect (QZE)

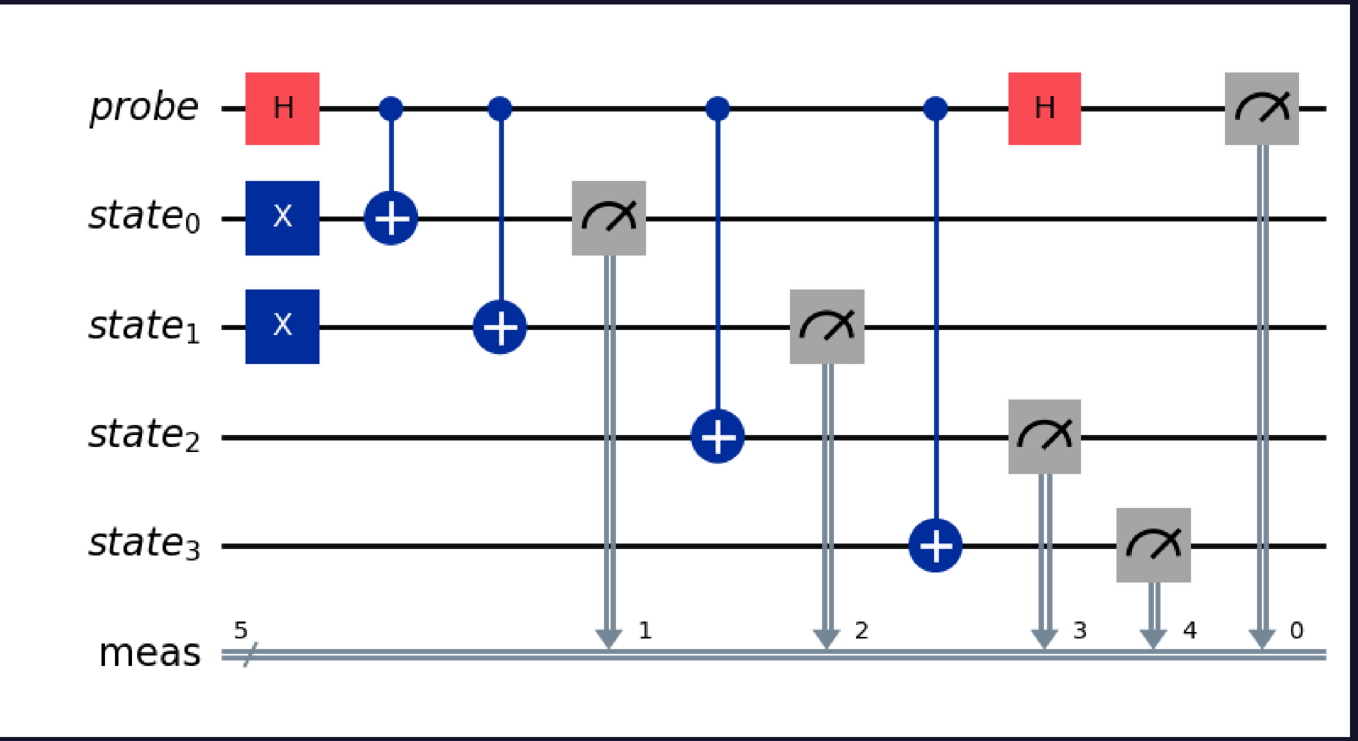
- We implemented an advanced "bomb tester" using the Quantum Zeno Effect.
- The Idea: A quantum system's evolution (like a qubit rotating from $|0\rangle$ to $|1\rangle$) can be "frozen" by rapid, repeated interactions.

The Zeno Circuit (Run N=15 times in one circuit)

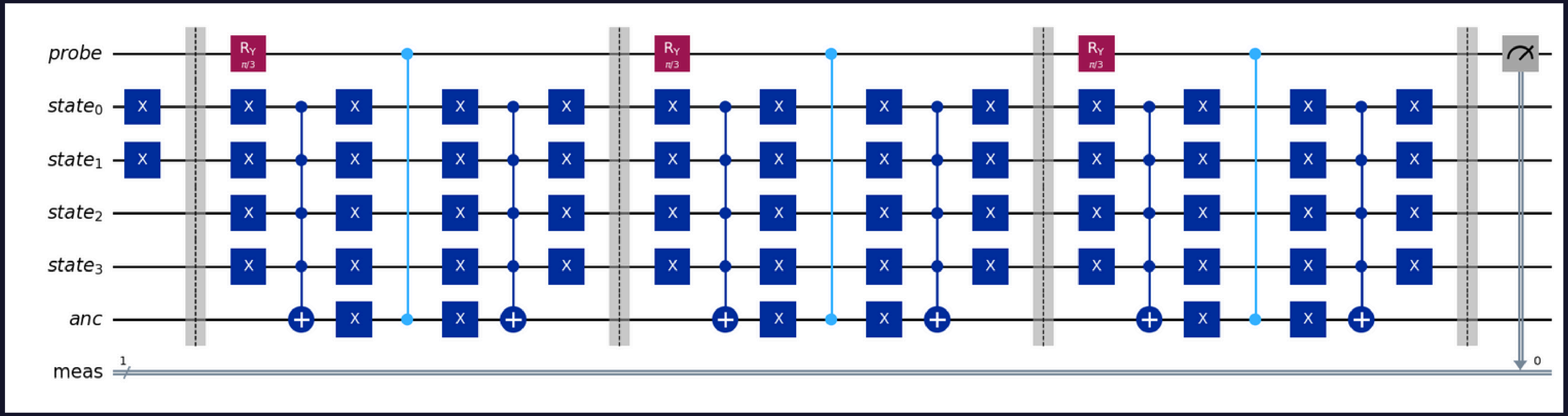
- Small Rotation: Apply a tiny Ry rotation to a "probe" qubit (moving it slightly from $|0\rangle$ towards $|1\rangle$).
- Oracle Check: Use an oracle (MCX gate) to check if any square in the row/column contains a ship.
- Interaction: A CZ gate "nudges" the probe qubit only if the oracle found a ship.
- Uncompute: Reverse the oracle to reset the state qubits, leaving them undisturbed.

How We Read the Results

- We only measure the probe qubit at the very end.
- "MISS" (No Ship): The probe rotated freely for 15 steps and is now measured as $|1\rangle$.
- "DETECT" (Ship Present): The 15 interactions "froze" the probe's rotation. It is still measured as $|0\rangle$.



Baseline Circuit Diagram



Zeno Circuit Diagram

Game Strategy (Radar)

Stage 1: Row scan (4 scans)

- Run Zeno on each row vector to find rows of interest.
- Row-level detections are exploratory (not counted in E.V.).

Stage 2: Column scan (4 scans per interesting row)

- For those rows, run Zeno on full column vectors (radar-style beam).
- Count a detection only if: column returns DETECT AND the cell (r, c) truly has ship.
- E.V. uses Stage-2 detections only: E.V. = Stage-2 Detections ÷ Hits.

Why this works

- Efficient narrowing (rows) + precise localization (columns).
- Interaction-free logic preserved throughout.

Results (Single Board + Robustness)

Single-Board Demo (representative)

- Baseline: Moderate E.V. (destructive measurements produce hits).
- Zeno: Stage-2 detections match the two ship cells; hits=0 ⇢ E.V. = ∞

Robustness (100 random boards)

- Baseline: finite E.V. (≈ 0.6–1.0 typical), non-zero hits.
- Zeno: E.V. = ∞ on all 100 trials; zero hits; 100% success rate.
- Improvement Factor: ∞× (prints as “inf x”).

Integrity checks implemented

- OR-oracle parity-safe (X–MCX–X; X on anc).
- Single-circuit QZE (N iterations inside, not cross-circuit aggregation).
- No classical shortcuts; probe-only decision.

Takeaways & Impact

- Interaction-Free Detection Achieved
- Detects ships without destroying them (0 hits → ∞ E.V.).
- Baseline: 4 rows + 4 columns; Zeno uses same radar coverage.
- E.V. strictly computed as Detections / Hits; Stage-2 only.
- Robust & Scalable
- Works across 100% of random placements (100/100 perfect).
- Clean architecture; easy to extend (larger grids / multiple ships).

This demonstrates a practical Elitzur–Vaidman bomb tester as a quantum radar, delivering a provable quantum advantage over destructive baselines.