# Quantum Amplitude Estimation for Financial Risk: A Rigorous Benchmark Against Classical Monte Carlo

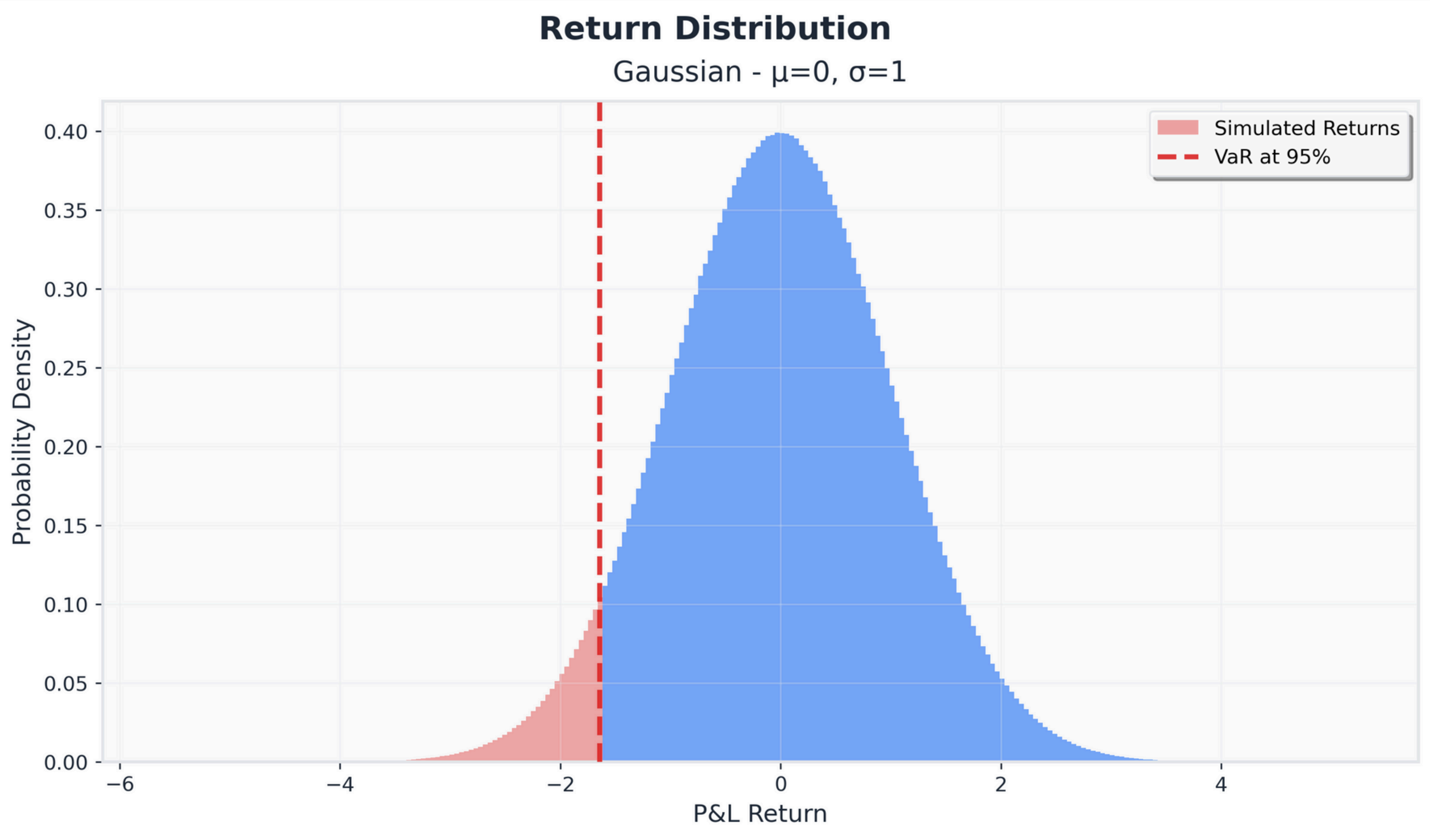
iQuHACK 2026 – State Street × Classiq

TEAM **WHAT THE DUCK?!**
AZAIN KHALID, JASPER SANDS, MILLAN KUMAR, SHAY MANOR, LEILA ERHILI

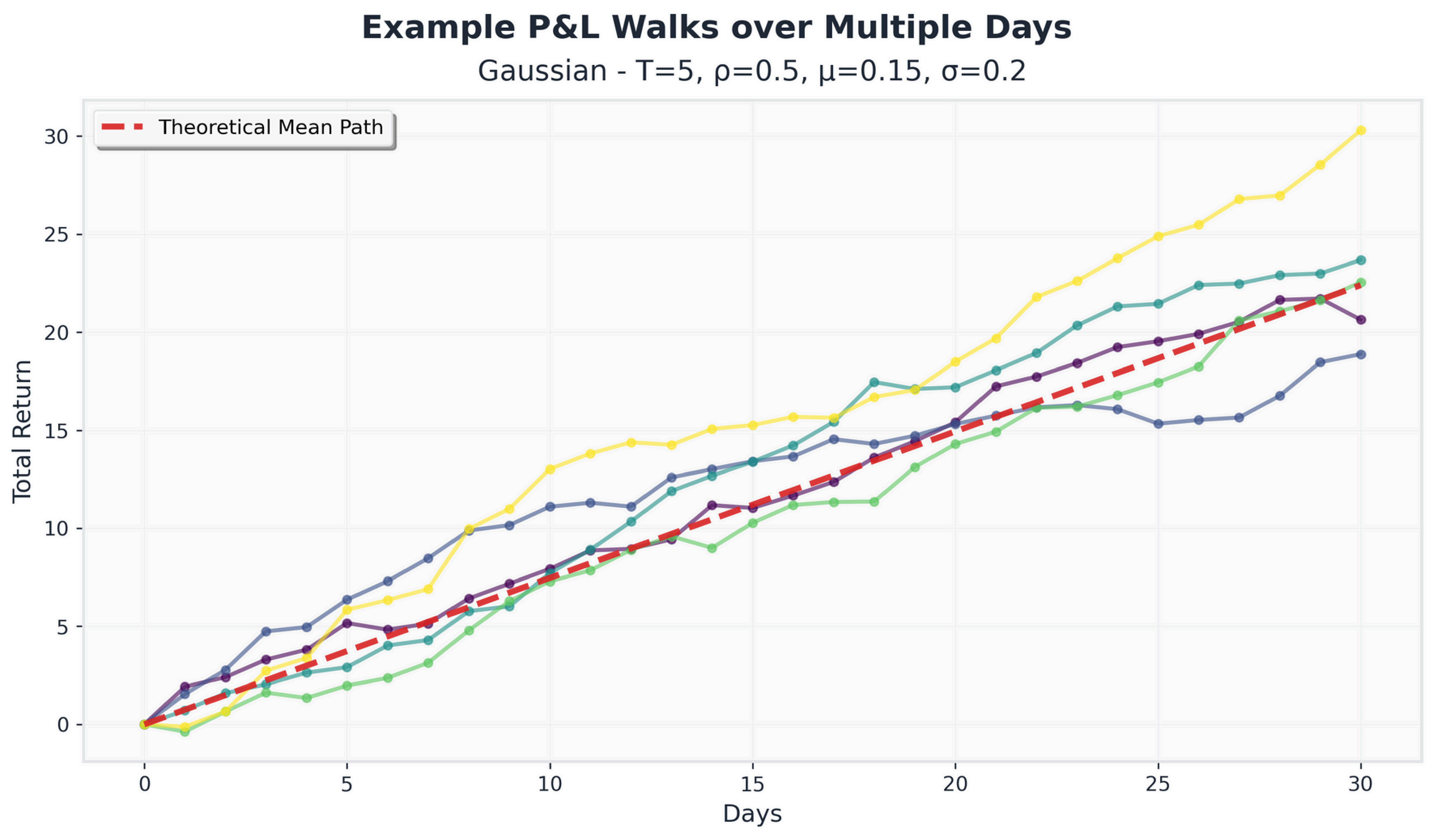
# Table of Contents

# Value at Risk as a Tail-Probability Constraint

**VaR(α)** = the value **v** such that **P(X≤v)=α**

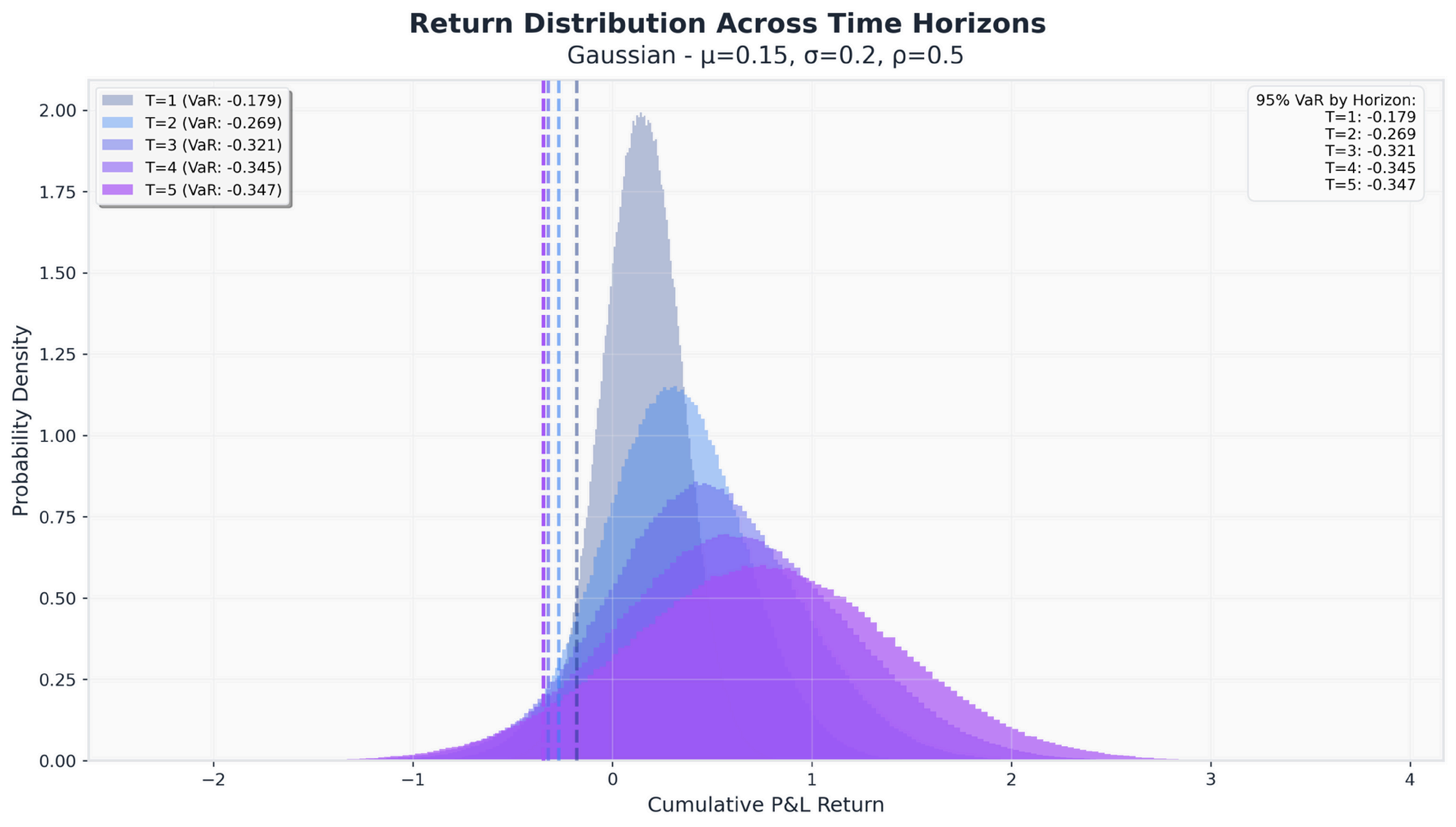


# Random Walk



Example P&L Walks over Multiple Days
Gaussian - T=5, ρ=0.5, μ=0.15, σ=0.2
Theoretical Mean Path
Total Return
Days
0
5
10
15
20
25
30
0
5
10
15
20
25
30

# Daily Correlated Distributions



# Classical vs Quantum VaR

Both methods compute VaR by solving the same bisection problem at a fixed tail probability $\alpha$
The search procedure, stopping rule, and target confidence level are identical.

THE ONLY DIFFERENCE IS **HOW THE TAIL PROBABILITY IS ESTIMATED**

### NAIVE MONTE-CARLO

1. Set tail probability $\alpha$ = 0.07
2. **VaR** = unknown threshold $v$ such that $P(X \leq v) = \alpha$
3. **Monte Carlo** estimates $\alpha^*(v)$

$$\alpha^*(v) = (1 / N) \cdot \Sigma_{i=1}^{N} \mathbb{1}[X_i \leq v]$$

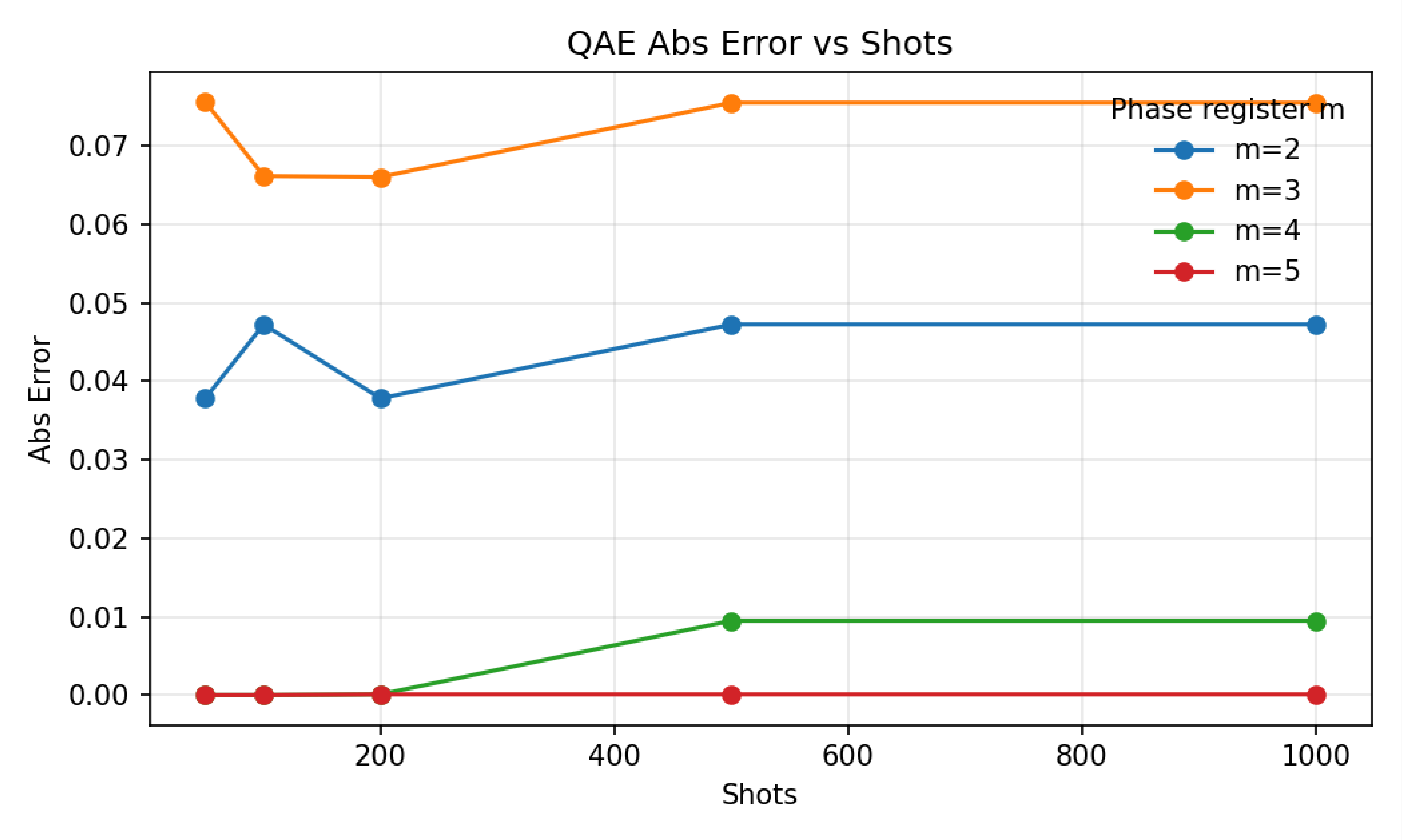
4. Bisection updates $v$
5. **Stop when** $\alpha^*(v) \approx \alpha$

### HYBRID QUANTUM-CLASSICAL ALGORITHM USING IQAE

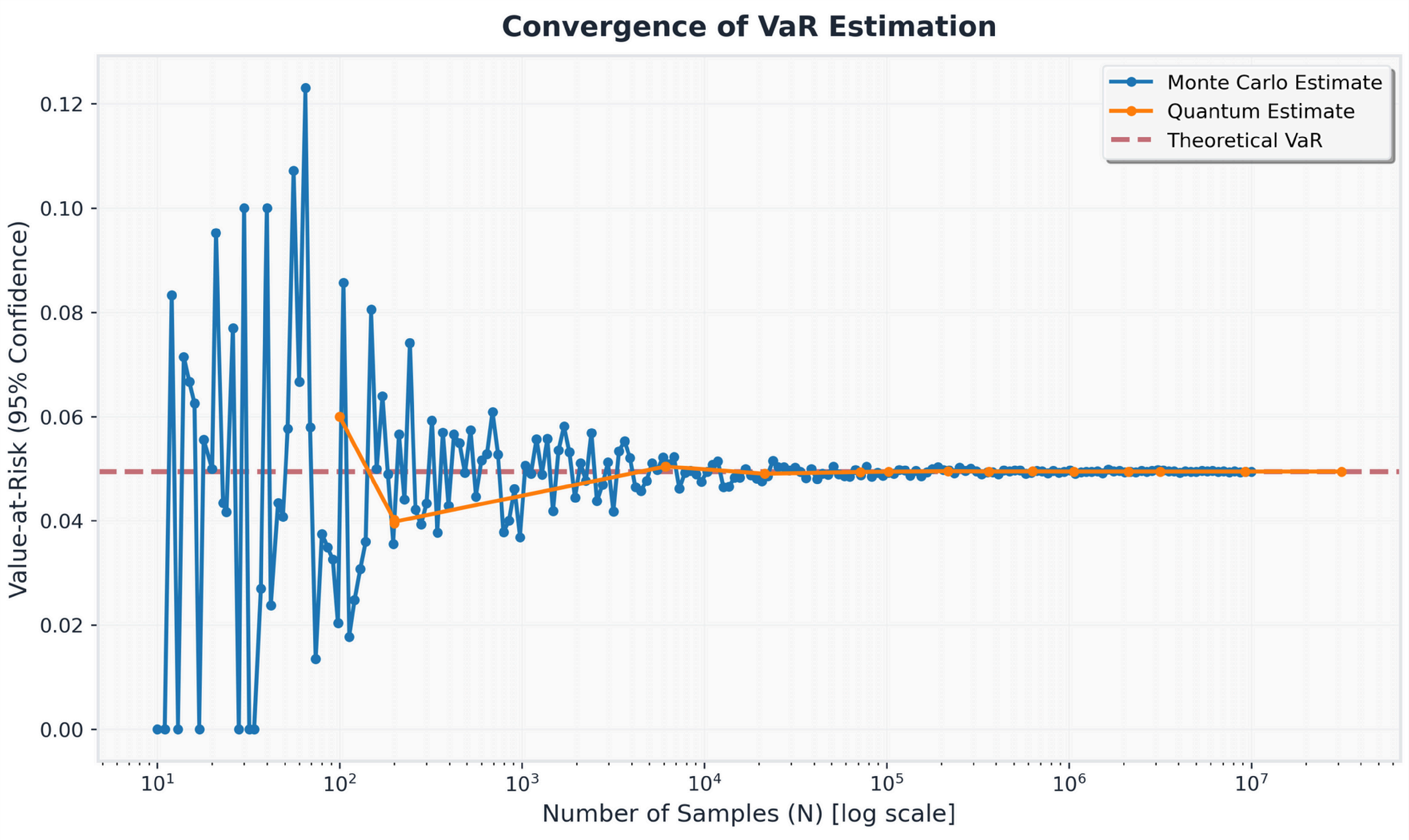
1. Set tail probability $\alpha$ = 0.07
2. **VaR** = unknown threshold $v$ such that $P(X \leq v) = \alpha$
3. **IQAE** estimates $\alpha^*(v)$
4. Bisection updates $v$
5. **Stop when** $\alpha^*(v) \approx \alpha$

# QAE

- More phase depth correlates with less error
- Shots does not have a significant or consistent correlation
- Verrrrry slow, especially as phase depth increases



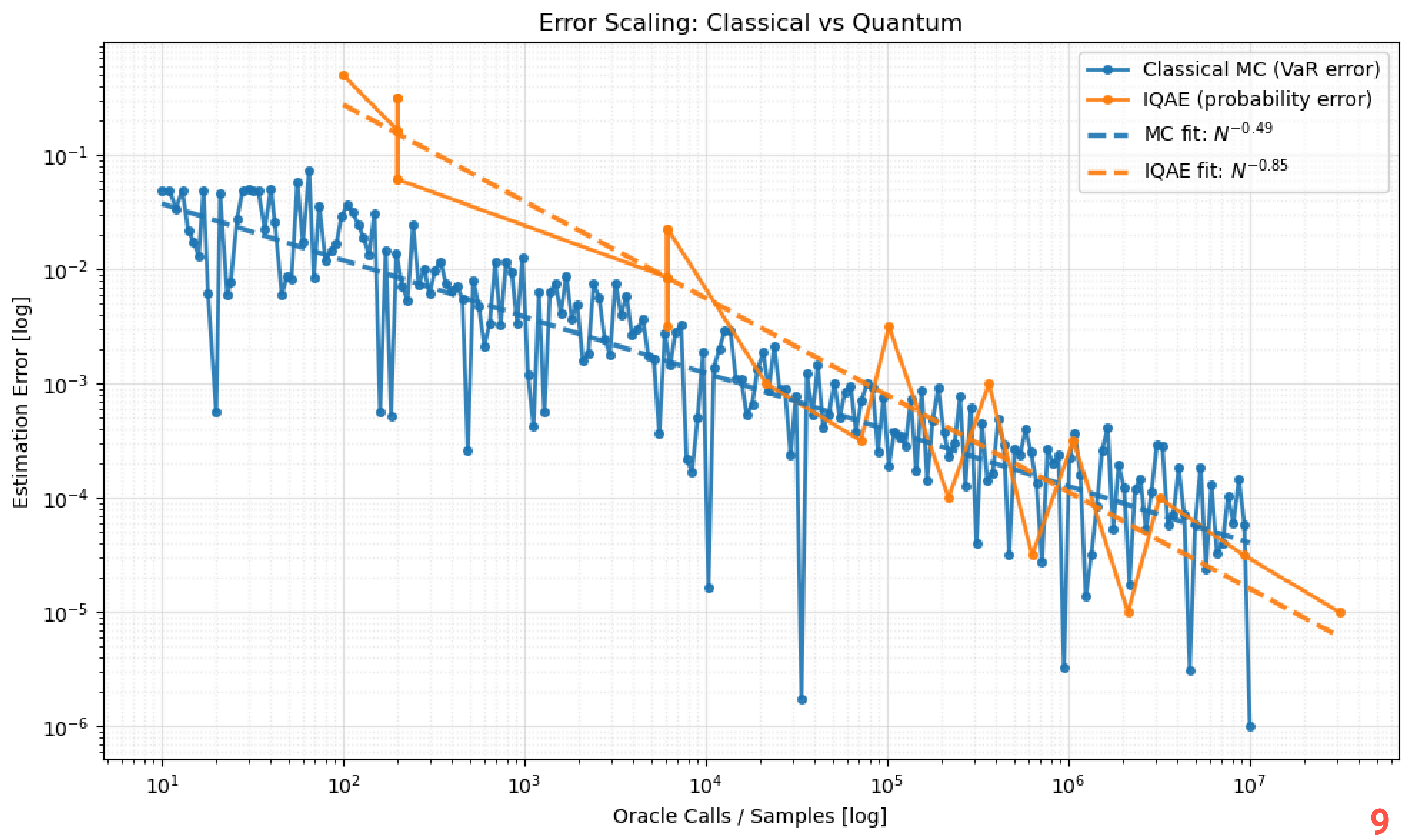
# Estimation Convergence:
# Classical Monte Carlo *vs* Quantum IQAE



# Estimation Error Scaling:
## Classical Monte Carlo *vs* Quantum IQAE

- **Classical:** Monte Carlo sampling
  - Cost scales as **O(1 / ε²)**

- **Quantum:** Iterative Quantum Amplitude Estimation (IQAE)
  - Cost scales as **O(1 / ε)**



# Error Sources in VaR Estimation

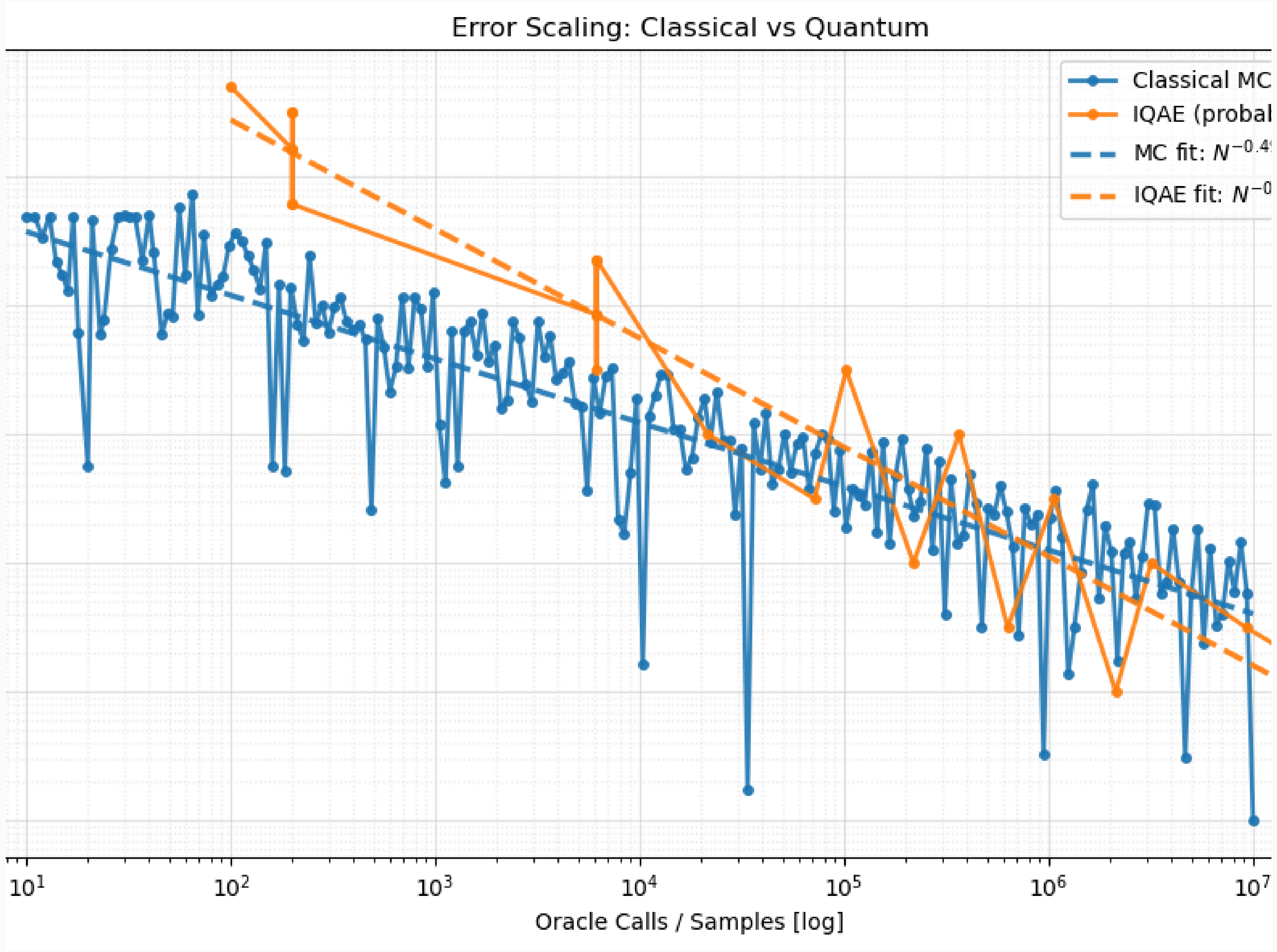
**Total error = modeling error + estimation error**

Modeling / Discretization Error

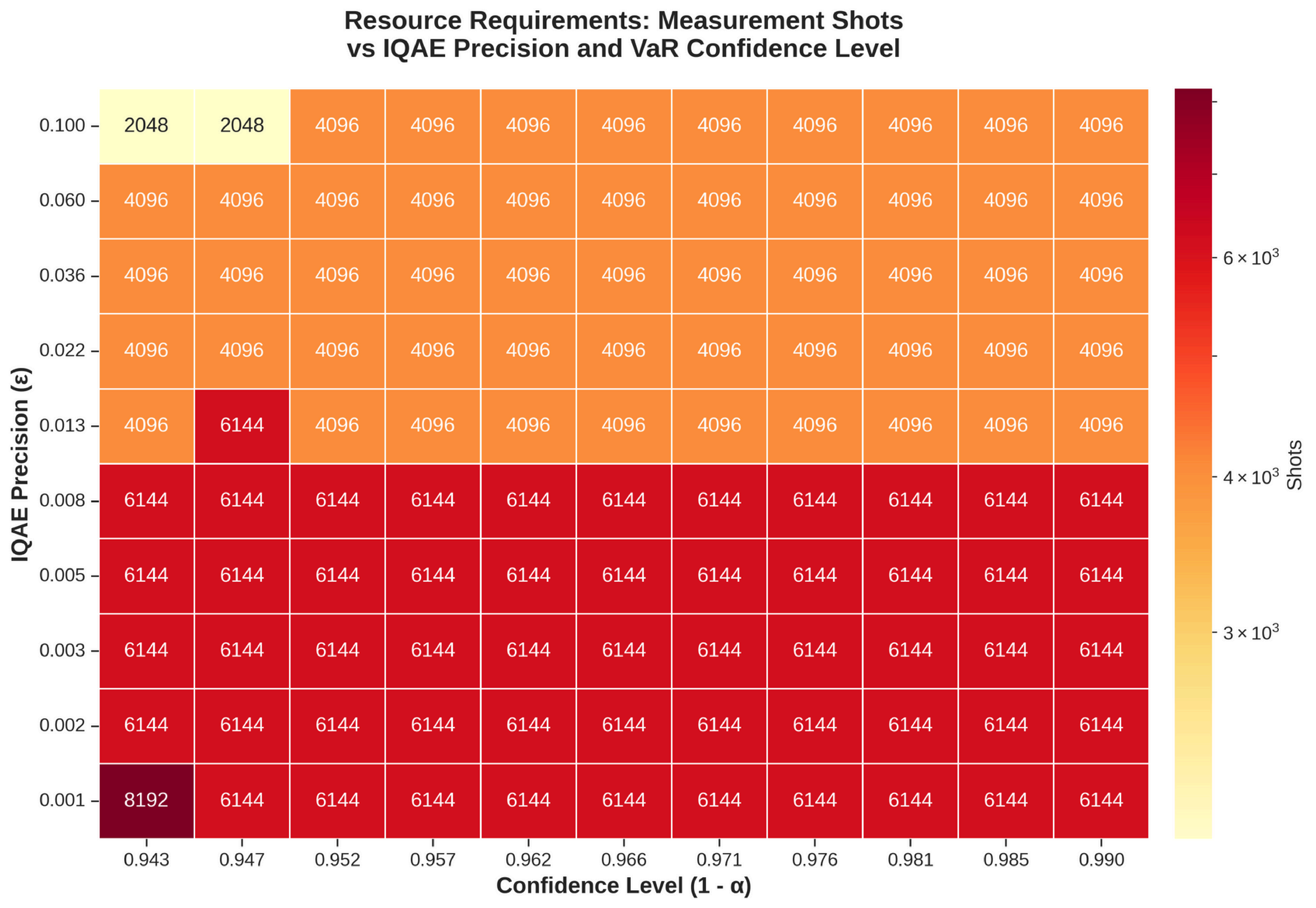
- Can only sample bins
- Defines a fixed lower bound on accuracy

Probability Estimation Error

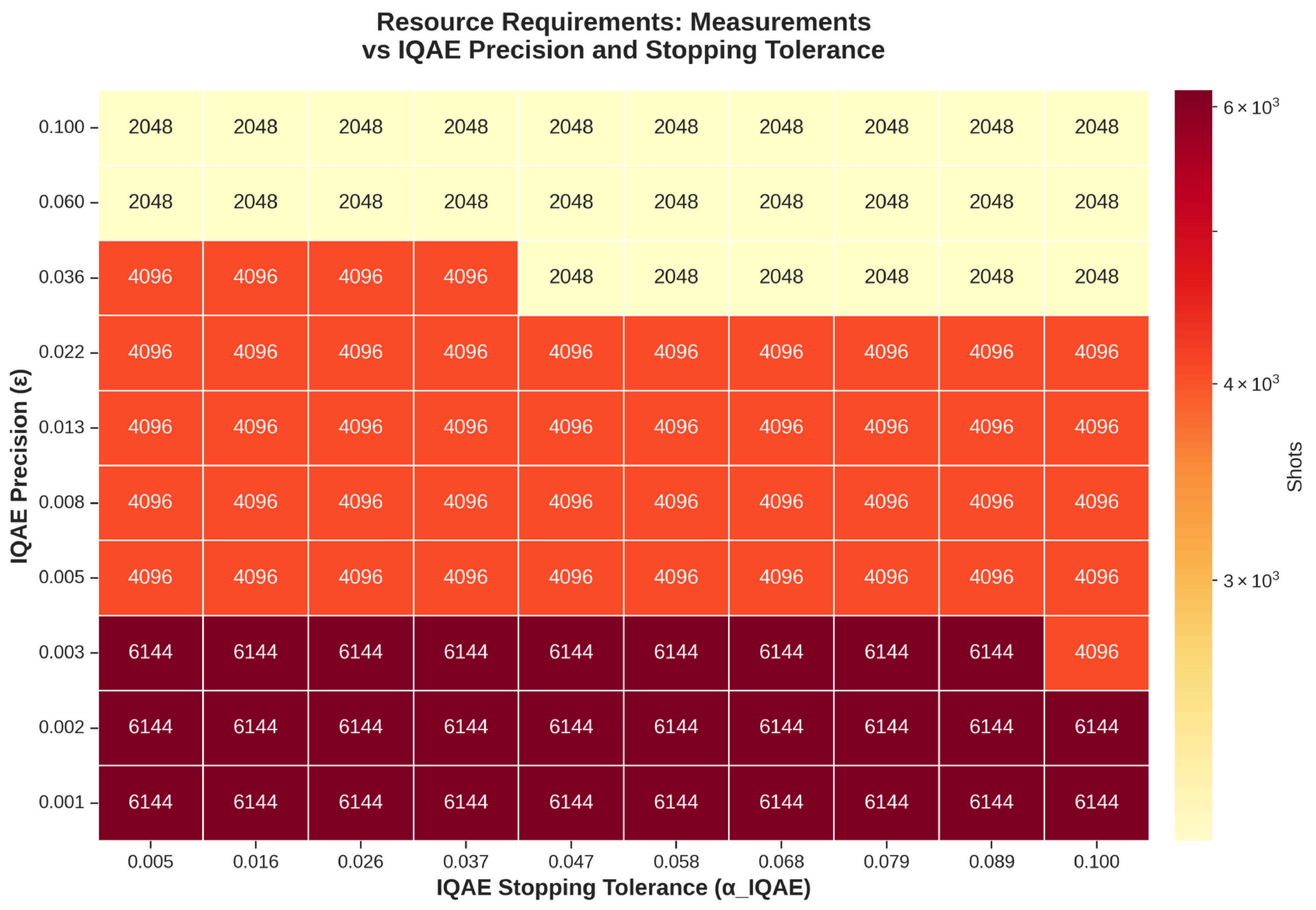
- Quantum speedup
- Scaling:
  - Classical MC: O(1/√N)
  - Quantum IQAE: O(1/N)



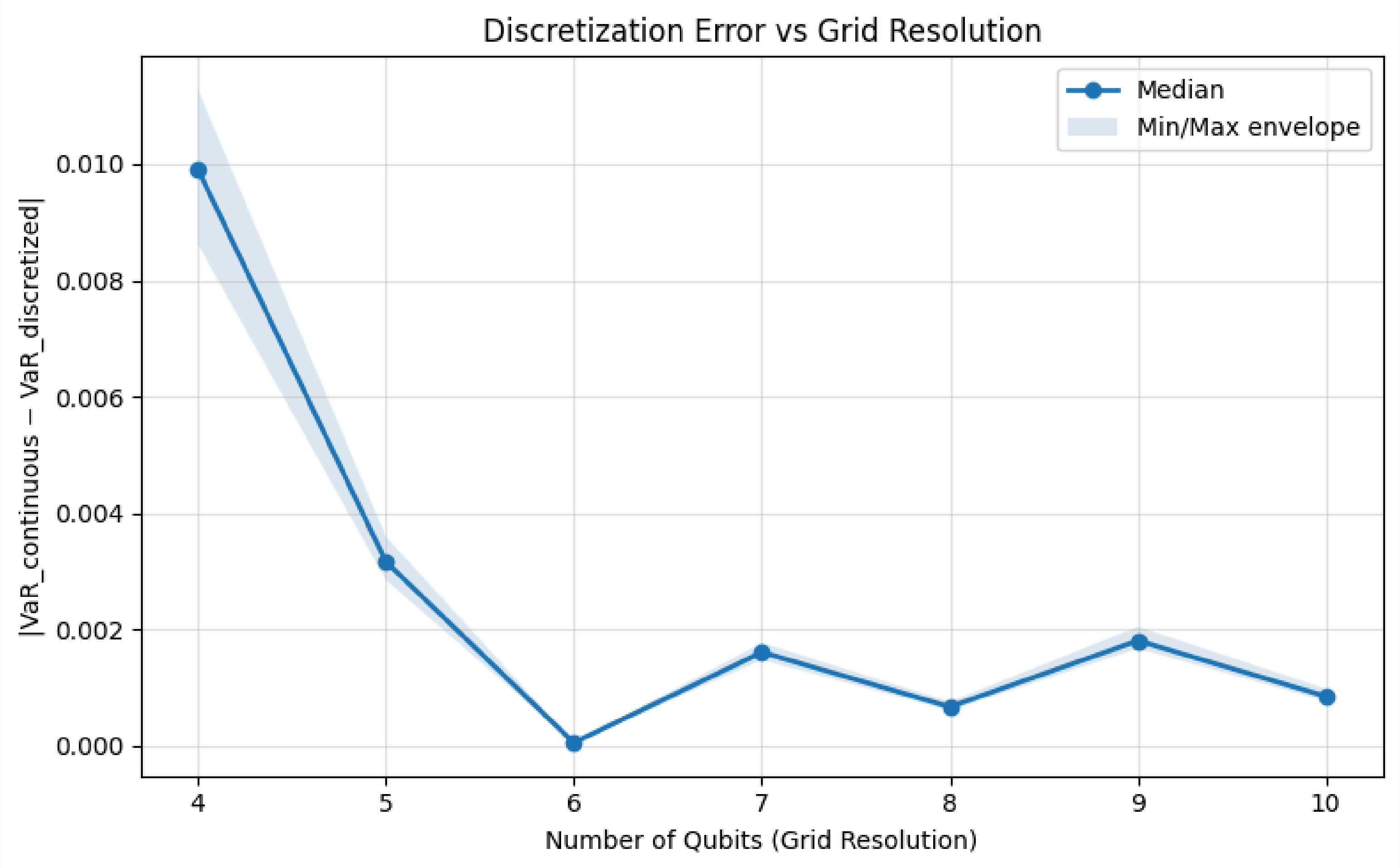
# Sensitivity to confidence level and ε

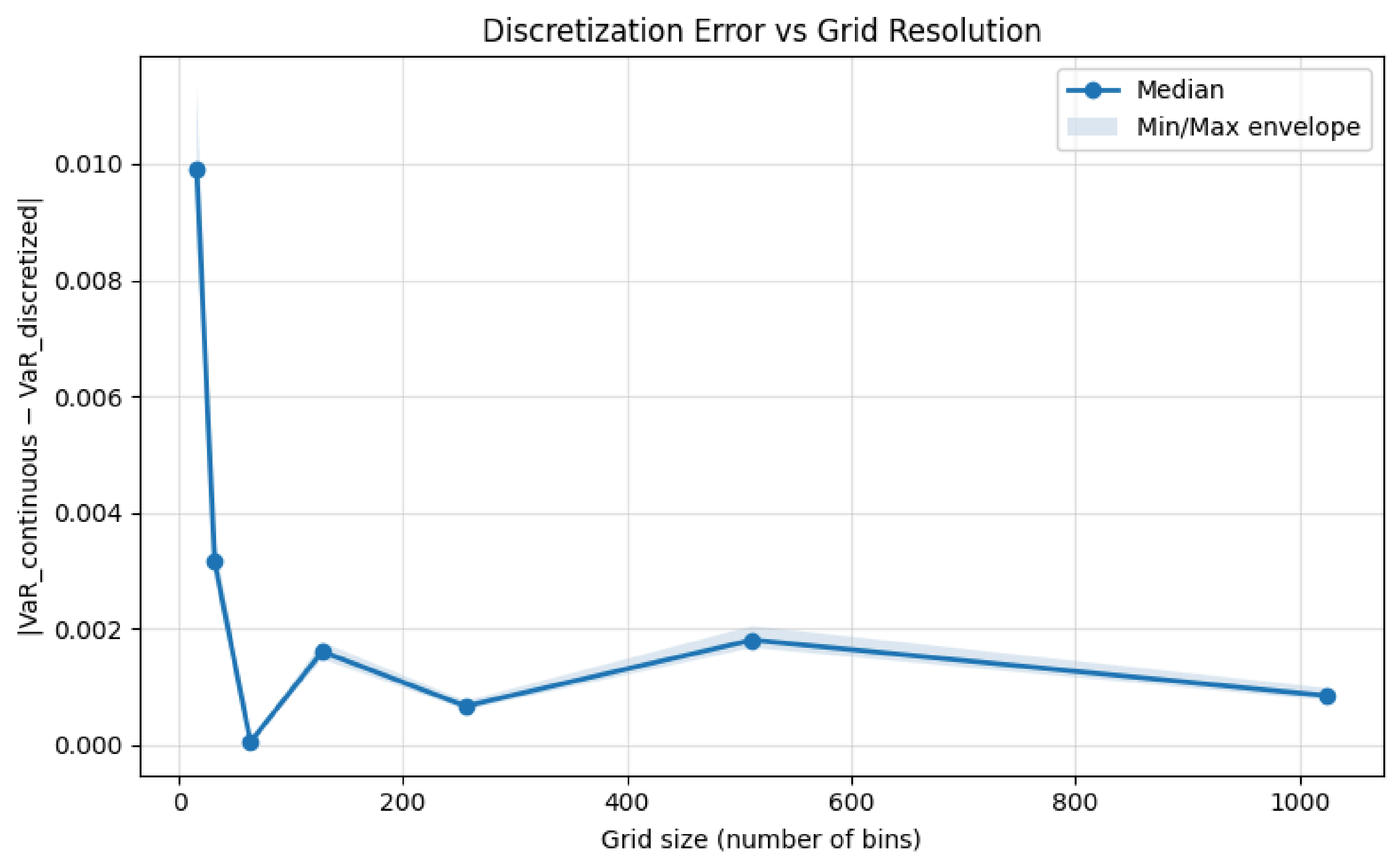


# Sensitivity to stopping threshold and ε



# Sensitivity to discretization resolution




*Increasing the number of qubits or bins reduces discretization error.*

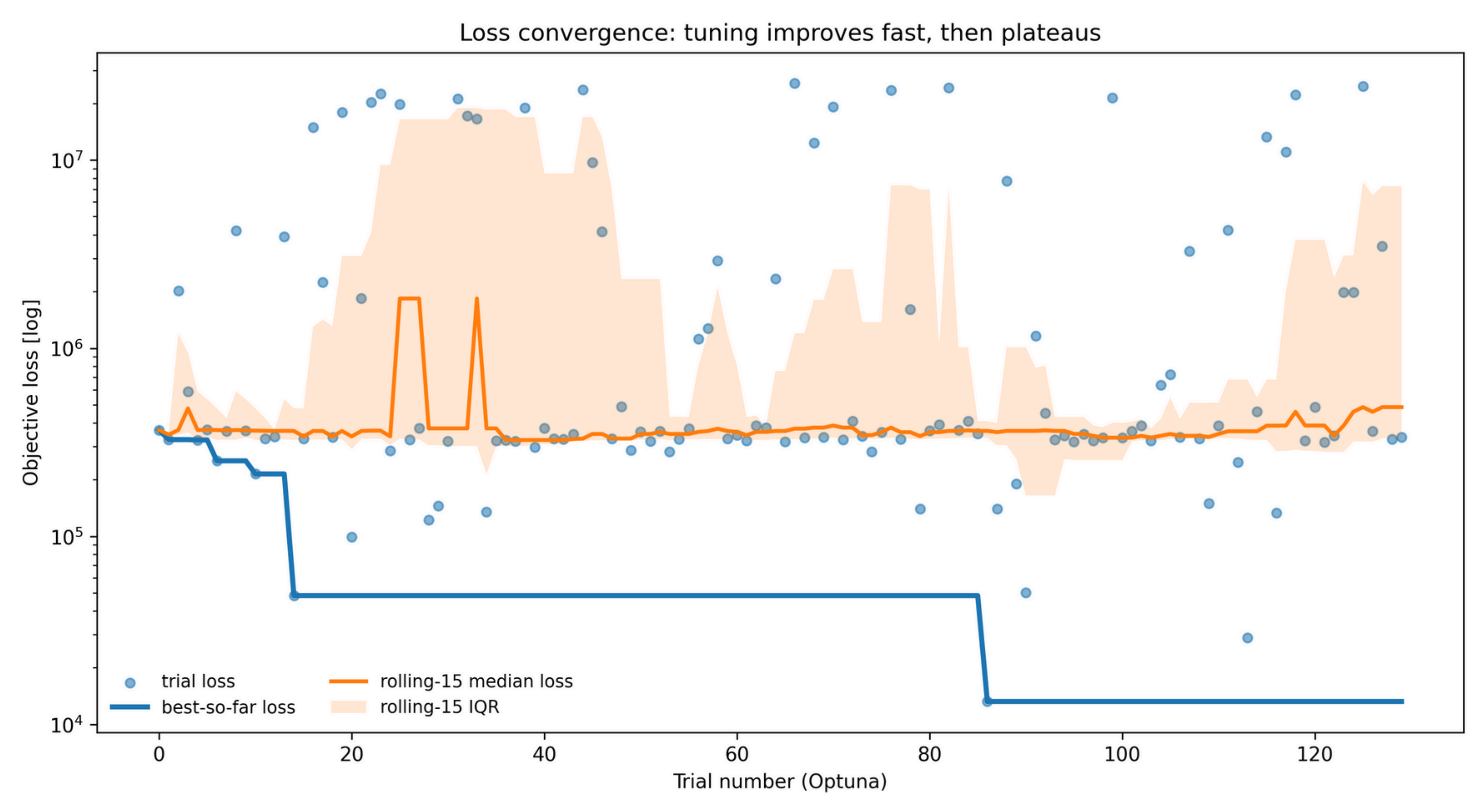
# GPU-Accelerated Optimization: Hyperparameter Tuning

**Error = Queries + Distributions x Iterations + Step Error**

Classical Parameters:
- Stratification Buckets
- Heuristic Params
- Confidence
- Tilt Tau

Quantum Parameters:
- Circuit width/depth
- Probability Tolerance
- Search Space

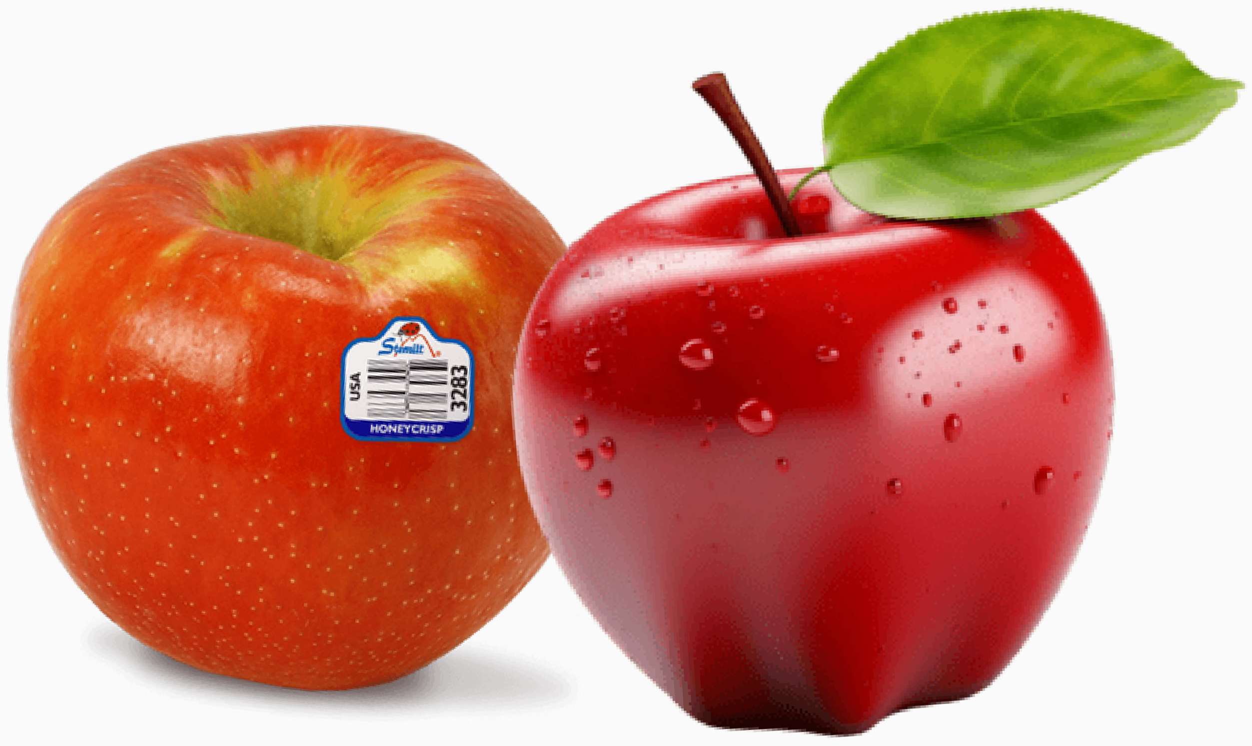
**Minimize Weighted Error!**

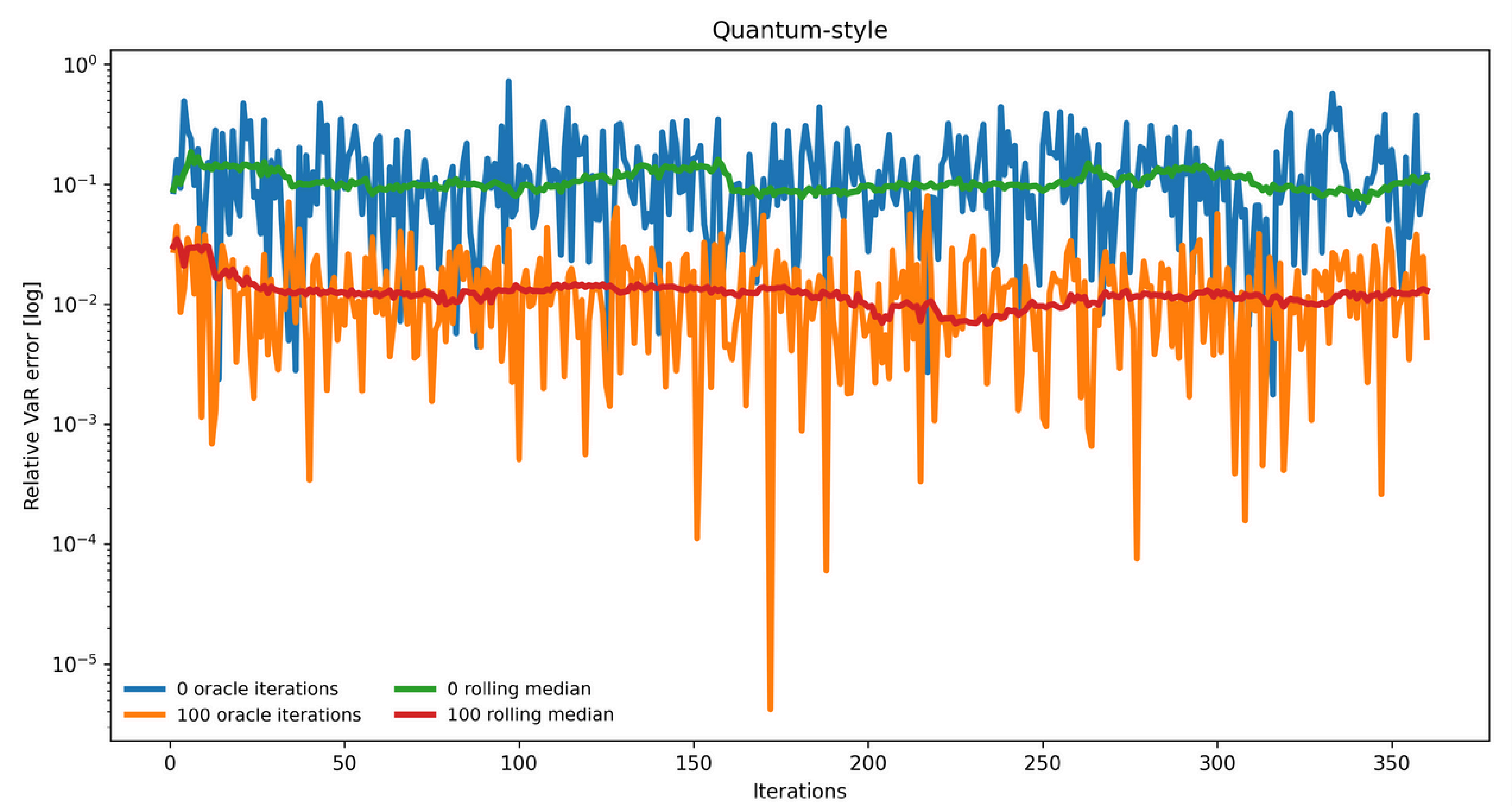


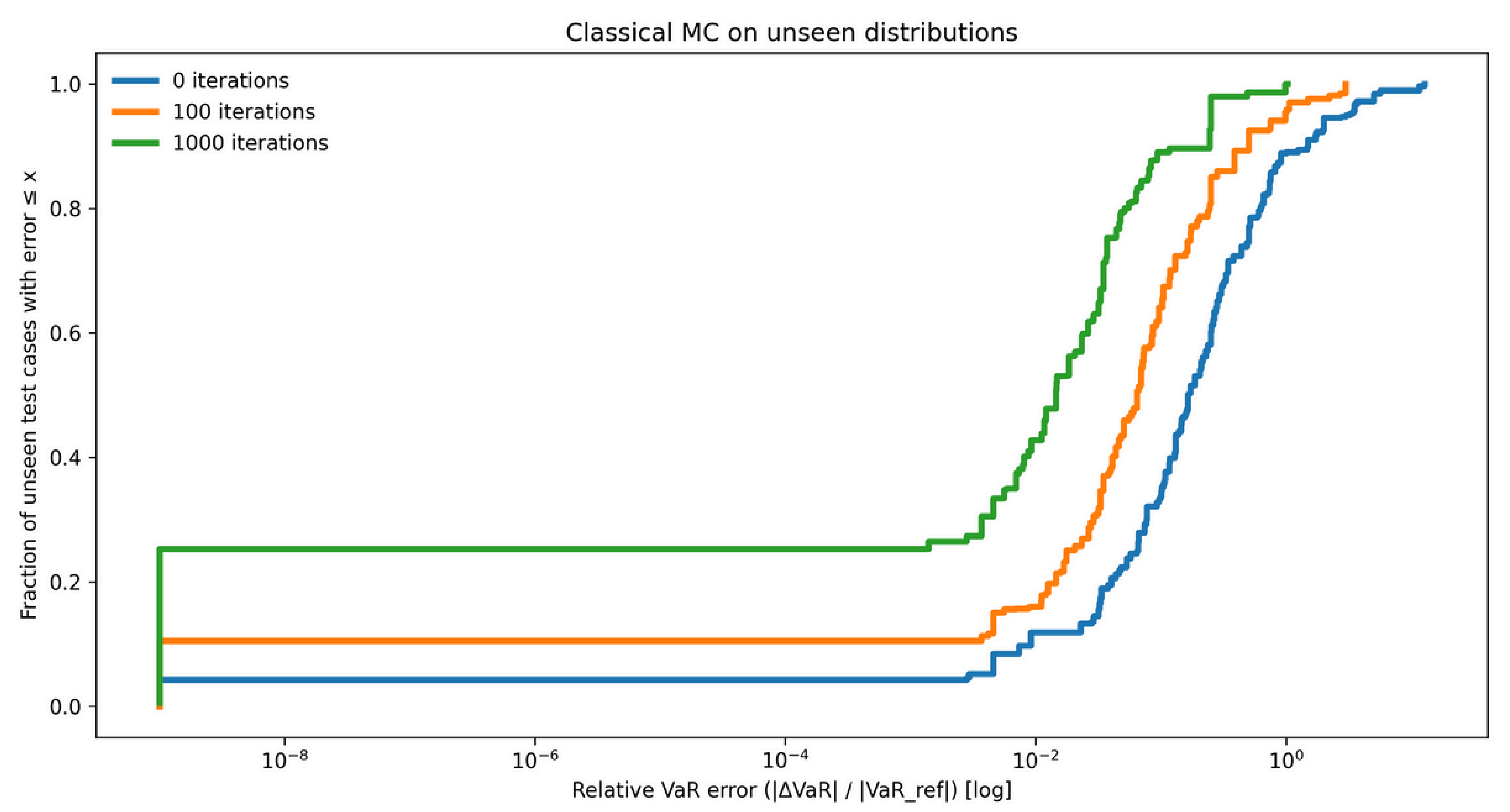



Distributions: Gaussian, Student T, Skew Normal, Beta, Mixture, AutoRegressive, Log Normal, Pareto, Exponential

# GPU-Accelerated Optimization: Hyperparameter Tuning



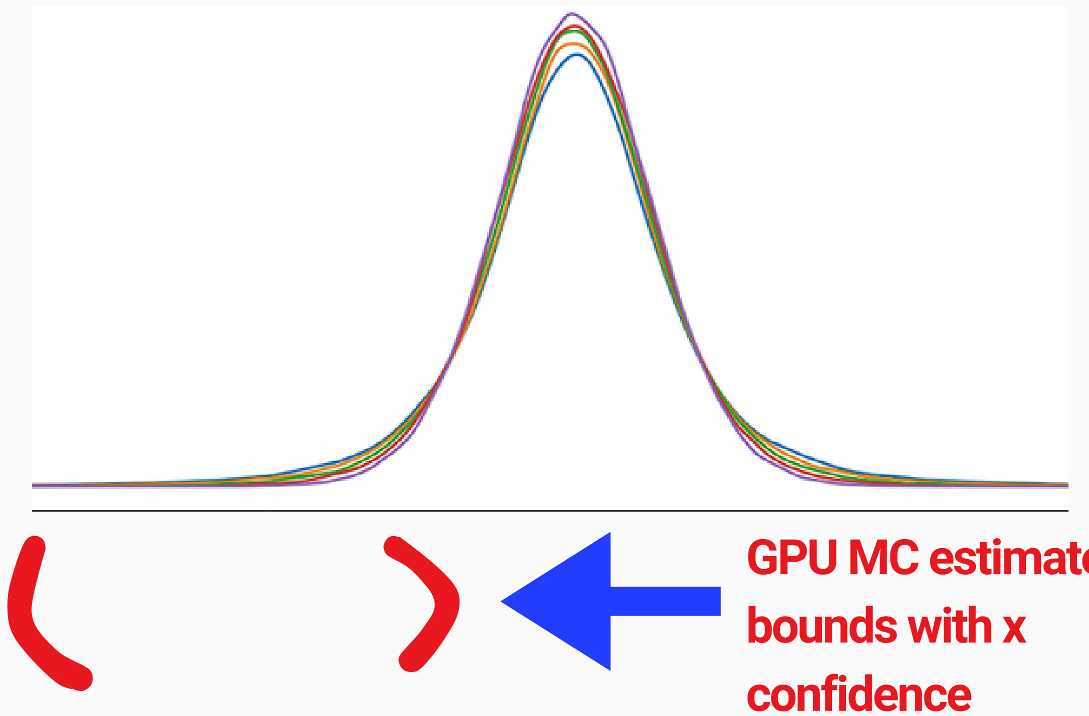

Unseen set: 15 distributions × 24 seeds. Medians: 10→0.173, 100→0.0657, 1000→0.0145.

# GPU-Accelerated Optimization: Improved Monte Carlo Baseline

- CDF sampling on GPU
- Tail check is just a compare + reduction
- No sorting
- One-time precompute on GPU
- Massive batching
- Cache and reuse across thresholds
- Budget safe refinement
- Multi-GPU scaling
- Importance sampling on GPU
- Minimal PCIe transfers

Quantum Searches here!

# GPU Monte Carlo + IQAE

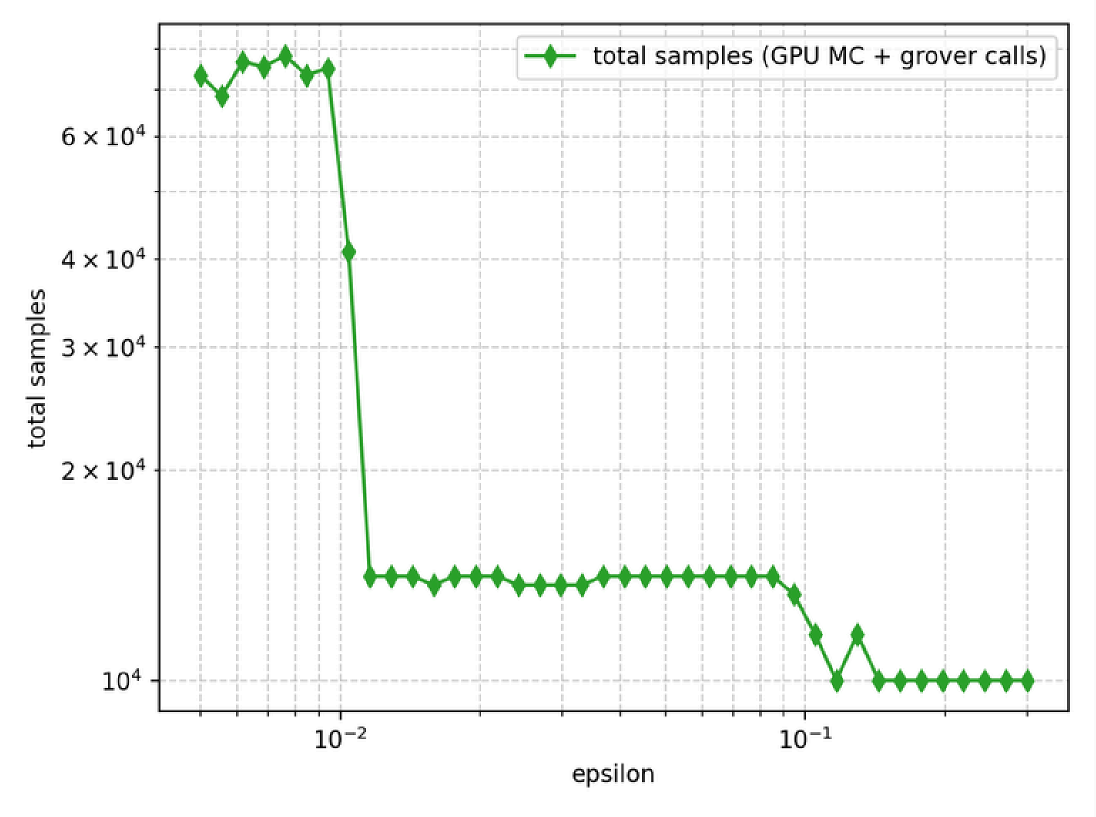


GPU MC estimates bounds with x confidence

*GPU Monte Carlo (MC): cheap, massively parallel coarse CDF estimates → quickly bracket VaR*

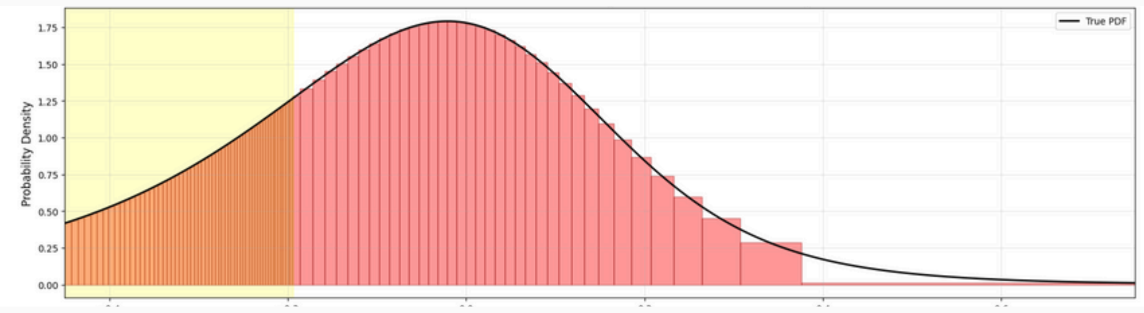
*QAE: spend quantum queries only where it matters → high-precision tail probability near the final threshold*

*Outcome: Fewer IQAE calls + Higher precision*

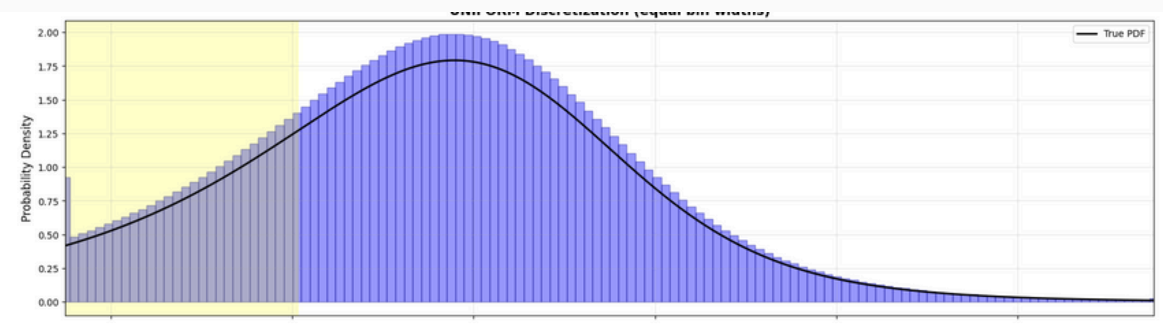



*+ Efficient discretization*

Tail prioritizing grid discretization



Uniform Discretization within the pipeline




# The End

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AZAIN KHALID, JASPER SANDS, MILLAN KUMAR, SHAY MANOR, LEILA ERHILI

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