Bayesian Optimization for QAOA on neutral atoms

HPCQC 2023, Cineca

Simone Tibaldi

OUTLINE

- What is Bayesian Optimization
- Why use it with VQAs
- Results

What is Bayesian Optimization

Optimization technique that converges quickly to a solution

Parameters

$(\theta_1, \theta_2, \cdots)$

Blackbox

Output

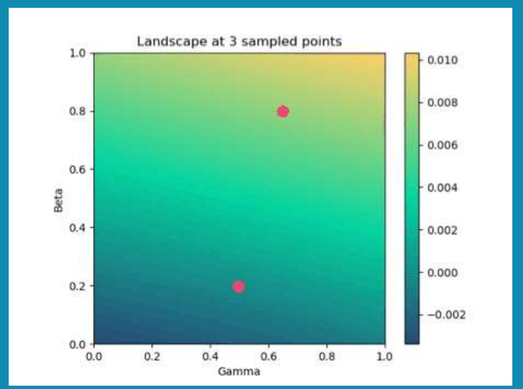
$E(\theta_1, \theta_2, \cdots)$

Acquisition Function

$$\mathbb{EI}(\vec{\theta}) = \sigma[\theta^\star \Phi(\theta^\star) + \phi(\theta^\star)]$$

$$\vec{\theta} = \max_{\vec{\theta}} \mathbb{EI}(\vec{\theta})$$

Gaussian Process

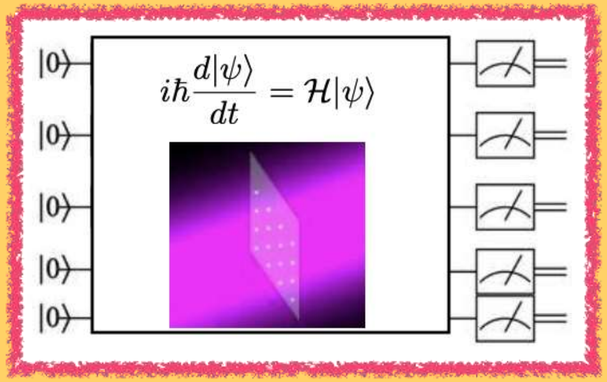


We use it for VQAs

[L Heneriet et al, Quantum (2020)]

Parameters

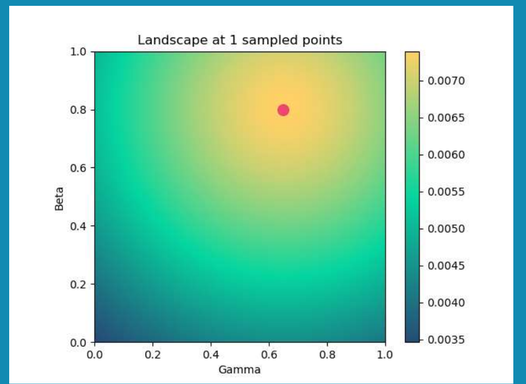
$(\theta_1, \theta_2, \cdots)$



Output

$E(\theta_1, \theta_2, \cdots)$

Gaussian Process

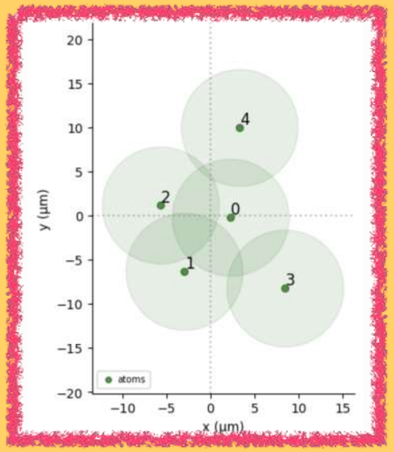


Acquisition Function

$$\mathbb{EI}(\vec{\theta}) = \sigma[\theta^\star \Phi(\theta^\star) + \phi(\theta^\star)]$$

$$\vec{\theta} = \max_{\vec{\theta}} \mathbb{EI}(\vec{\theta})$$

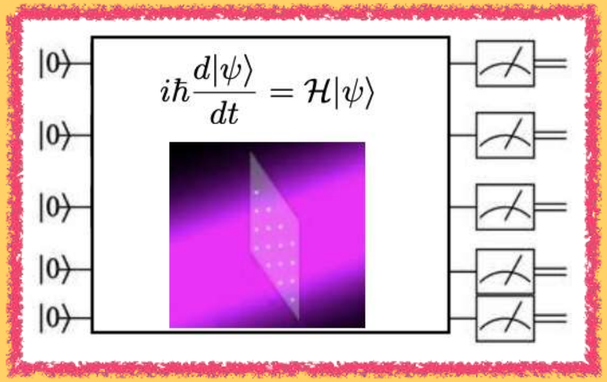
More details on the VQAs



Parameters

$(\theta_1, \theta_2, \cdots)$

[L Heneriet et al, Quantum (2020)]



Output

$E(\theta_1, \theta_2, \cdots)$

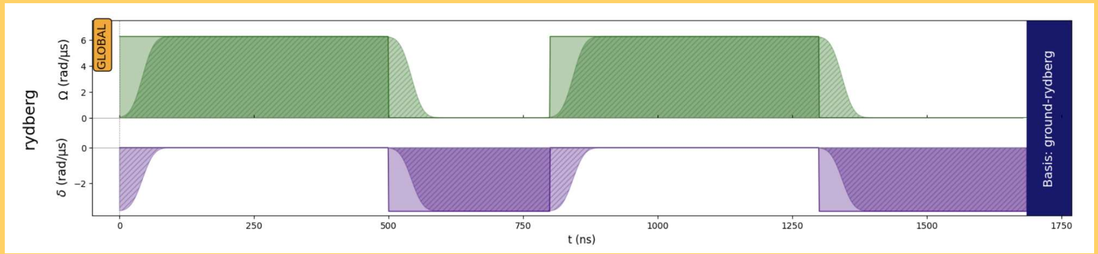
$$H_{MIS} = -\sum_i x_i + \sum_{(i,j)\in E} x_i x_j$$

$x \in \{0, 1\}$

$$H_M = \Omega(t) \sum_i \sigma_i^x$$

$$H_C = -\delta(t) \sum_i n_i + U_{i,j} \sum_{(i,j)\in E} n_i n_j$$

$$R = \frac{E}{E_0}$$



Challenges of this Optimization

Parameters constraints

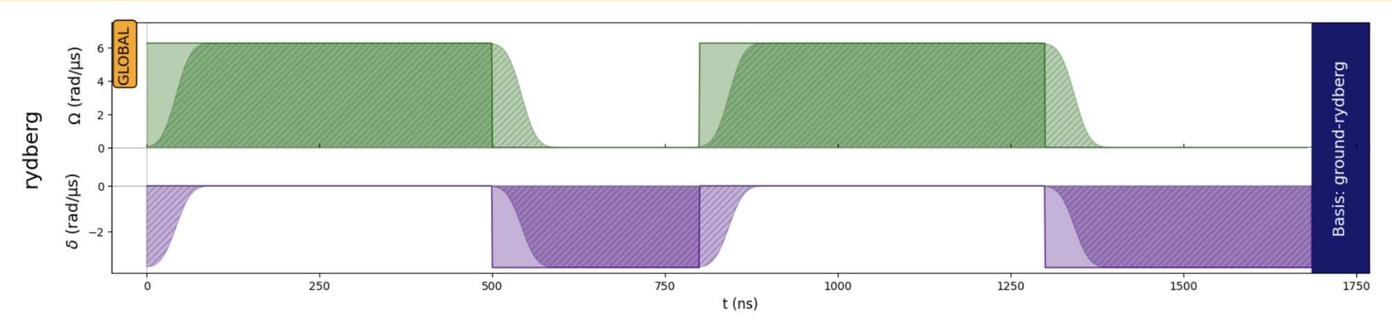
- Sum under 4000 ns (decoherence)
- Minimum 100 ns per pulse

Time budget

- How many shots per step?
- Repetition rate ~ 3 Hz

Noise

State preparation and measurement (SPAM)

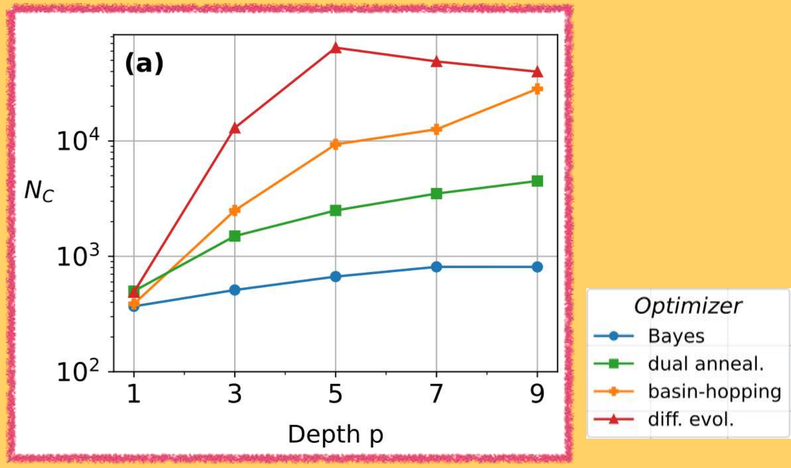


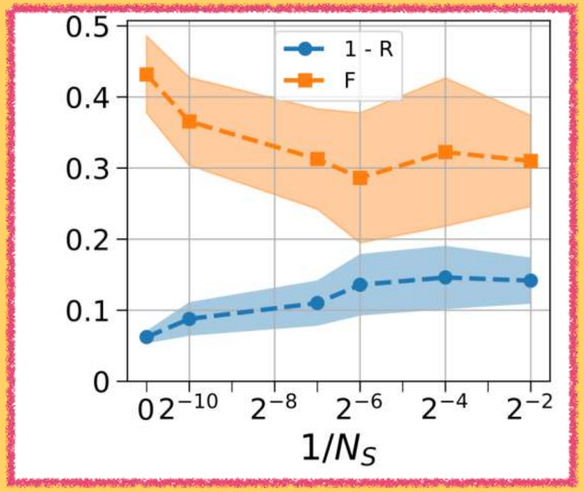
- Limited depth (up to p ~ 5)
- Optimization with Linear constrains

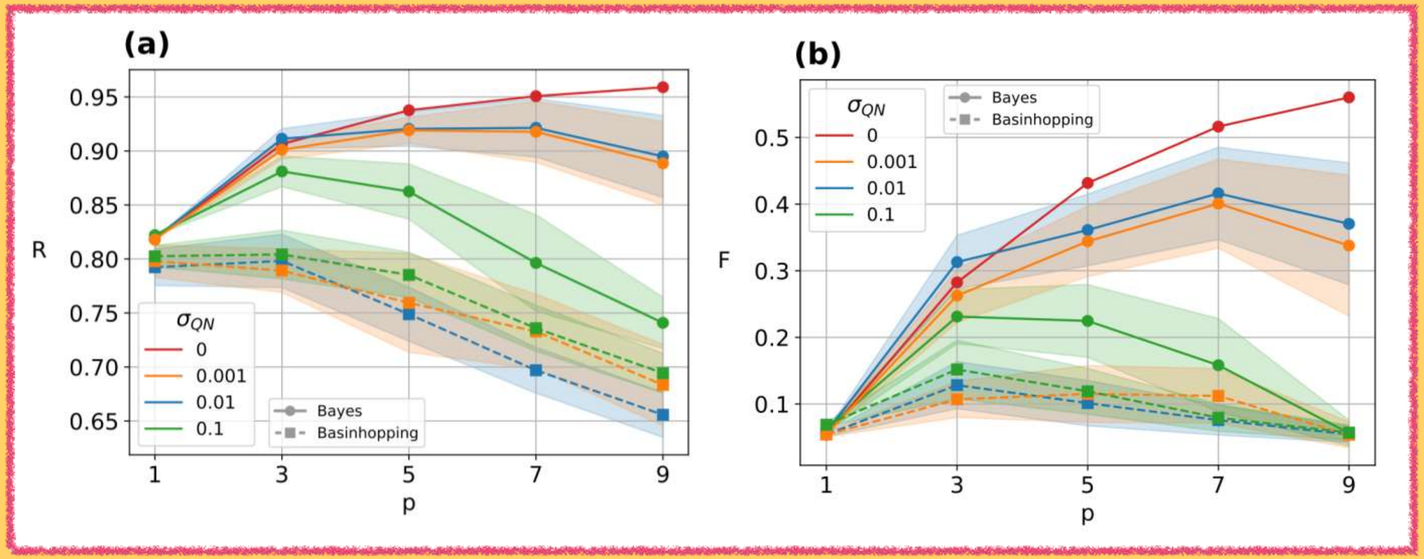
Low Measurement, few-shot: simulation results

Time budget

- How many shots per step?
- Repetition rate ~ 3 Hz







[Bayesian Optimization for QAOA, Tibaldi et al, IEEE Transaction on Quantum Engineering (2023)]

SPAM errors

MOSTLY READOUT PROBLEM

- FALSE POSITIVE: Measure 0 instead of 1

$$\varepsilon \sim 5\%$$

- FALSE NEGATIVE: Measure 1 instead of 0

$$\varepsilon' \sim 8\%$$

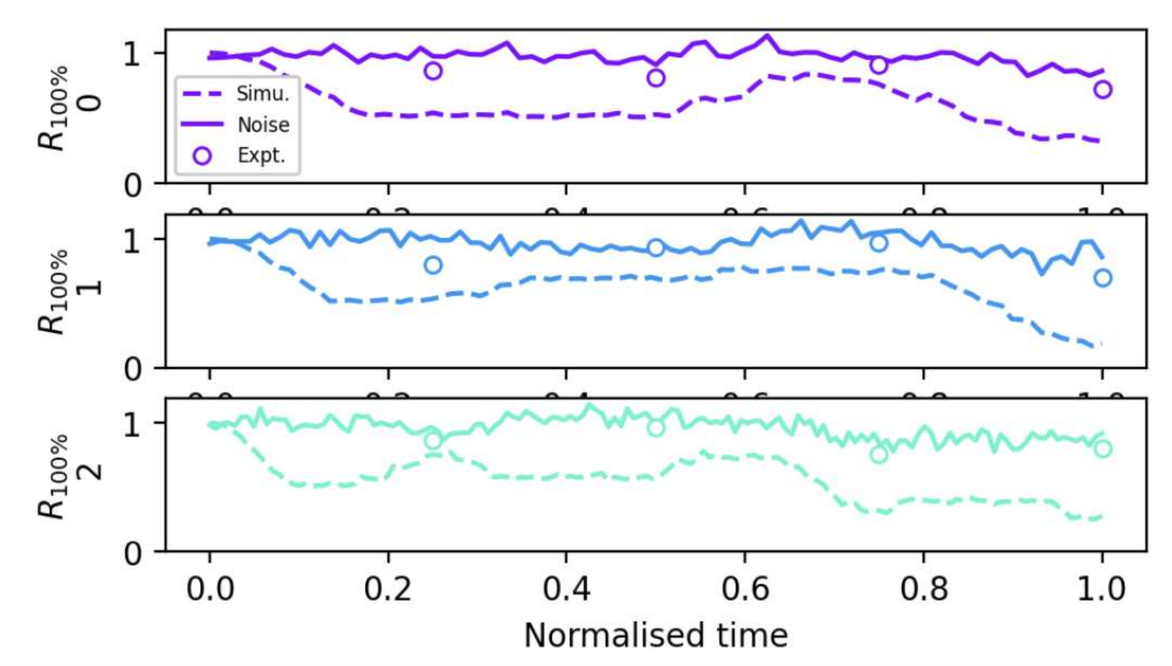
Fight it by discarding most—energetic bitstrings

Noise

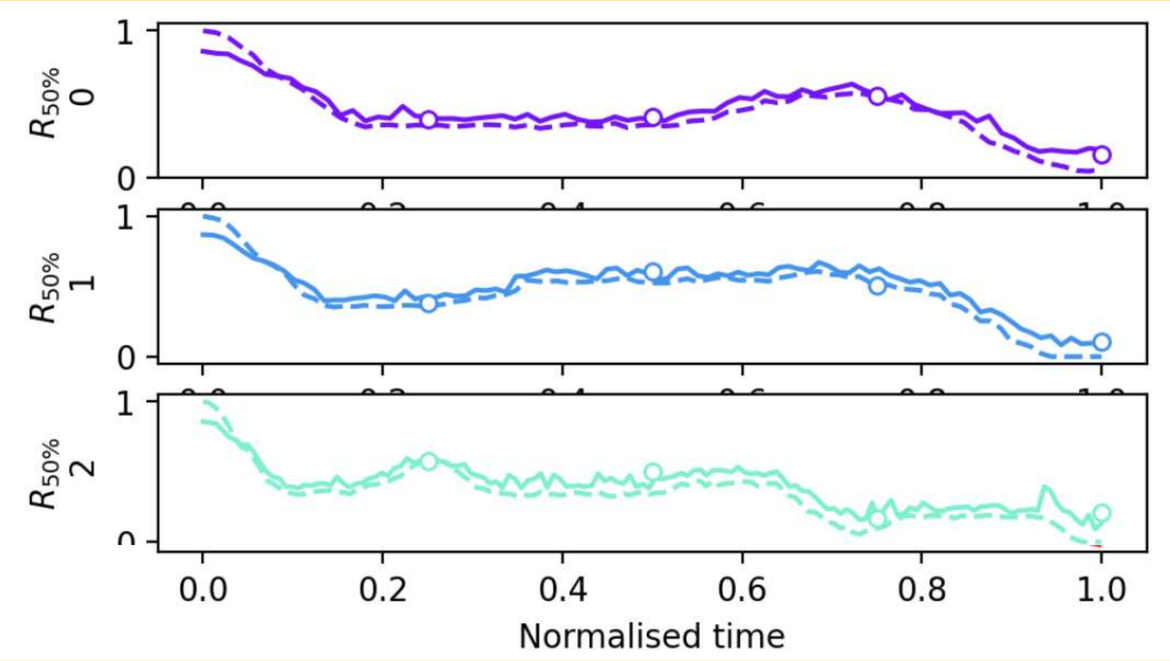
State preparation and measurement (SPAM)

A few sequences: correcting for SPAM

Uncorrected



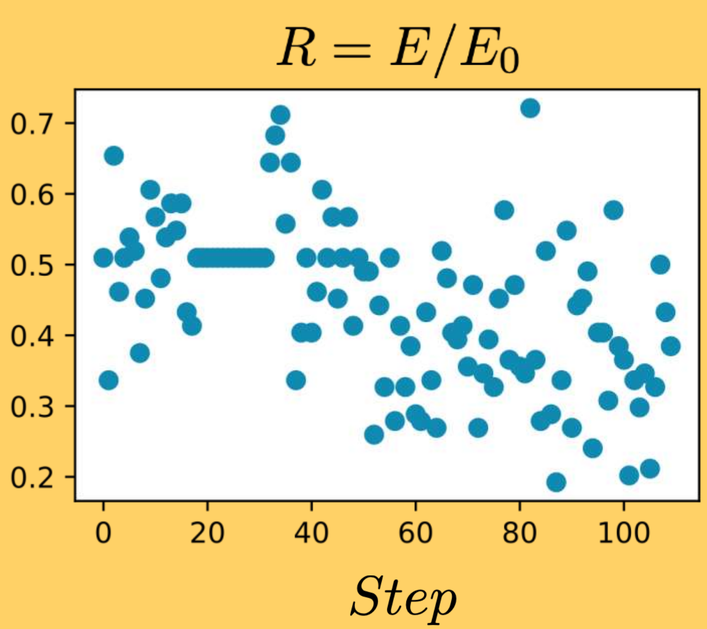
Corrected

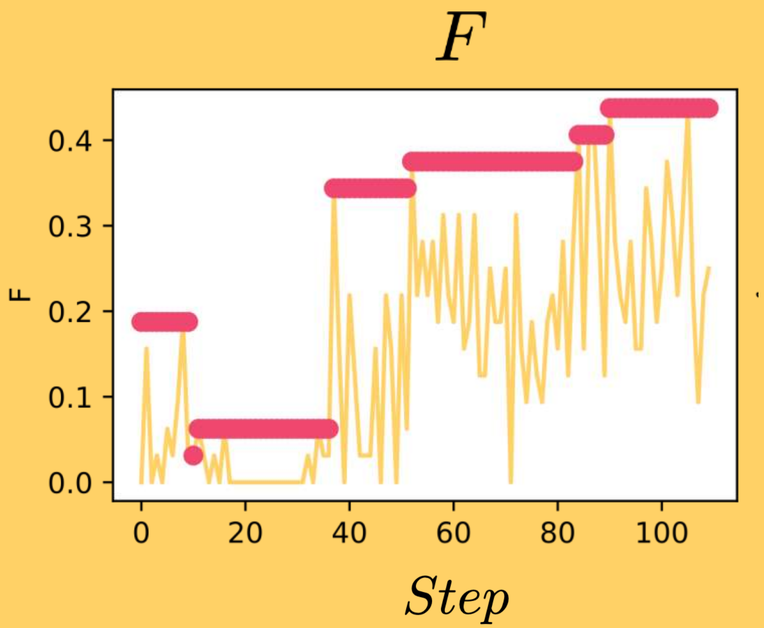


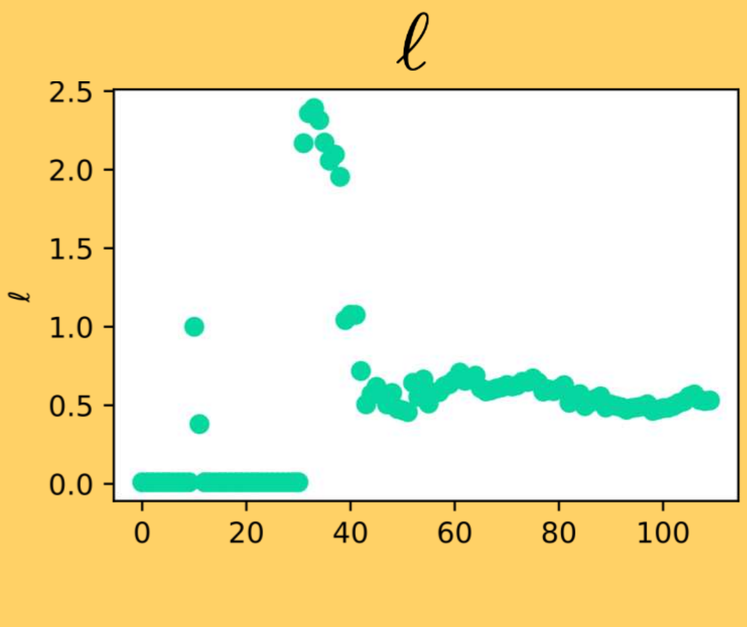
$$R = \frac{E}{E_0}$$

Finding balance between curing ratio and # measurements.
Good agreement with discarding 20%

BO: p=2, N=6, step=100, shots=32

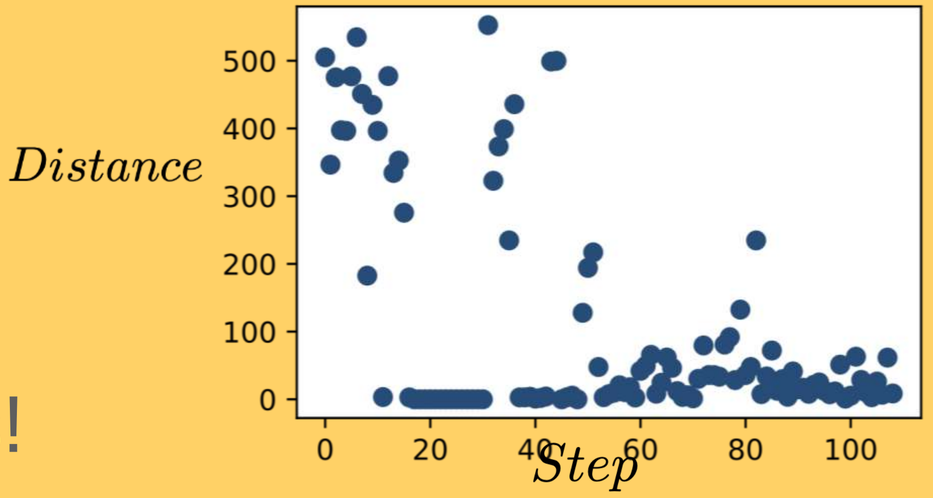






We keep track of many parameters, including:

- Approximation ratio
- Fidelity
- Correlation length
- Distance between consecutive points



Currently testing on 11 and 25 qubits!

Conclusions

We are testing on a neutral atom platform an optimization procedure that:

- Reduces the number of calls to the circuit
- Can optimize even with few measurements and with noise
- Seems robust once SPAM is taken into account