

# Variational Fast Forwarding (VFF) for Quantum Simulations<sup>1</sup>

- Hamiltonian Simulation is one of the most anticipated application of quantum computing. However, known algorithm with optimal asymptotic scaling will only be relevant on fault-tolerant quantum devices, as they are limited by the decoherence time of the hardware.
- Variational Fast Forwarding uses short depth circuits even for long simulation time, suitable in NISQ - era. It aims at approximating a diagonal representation of the Hamiltonian by optimizing an ansatz represented as a quantum circuit to approximate the eigenstates and the eigenvalues of the Hamiltonian.
- This enables a fast forward time evolution, as we can efficiently exponentiate the Hamiltonian in the following way:  $e^{-iHt} = (e^{-iH\Delta t})^N \approx W(\theta)D(\gamma, \Delta t)^N W(\theta)^\dagger$ . This permits to forward beyond the decoherence time.

**Can we find better ansatz for  $W$ ?**

**Can we use perturbative layerwise training to tackle complexe hamiltonians?**

**Is this method competitive against Trotter evolution or exact diagonalisation?**

[1] Cristina Cîrstoiu et al., *Variational fast forwarding for quantum simulation beyond the coherence time*, NpJ Quantum Information 6:82 (2020).

# Technical details:

**Goal:** build a qiskit package of the VFF algorithm, which would permits the user to compute the time evolution for any Ising-type Hamiltonian beyond the decoherence time. We also hope to find better ansatz and to test a layerwise training strategy while perturabting the Hamiltonian<sup>[2]</sup>.

- Ansatz: trainable feature map, build on the inherent symmetry of the Hamiltonian
- Layerwise training: start with a simple Hamiltonian and train  $W$ . Then add a term to the Hamiltonian and layers to  $W$  initialiased at the identity and train  $W$  again.

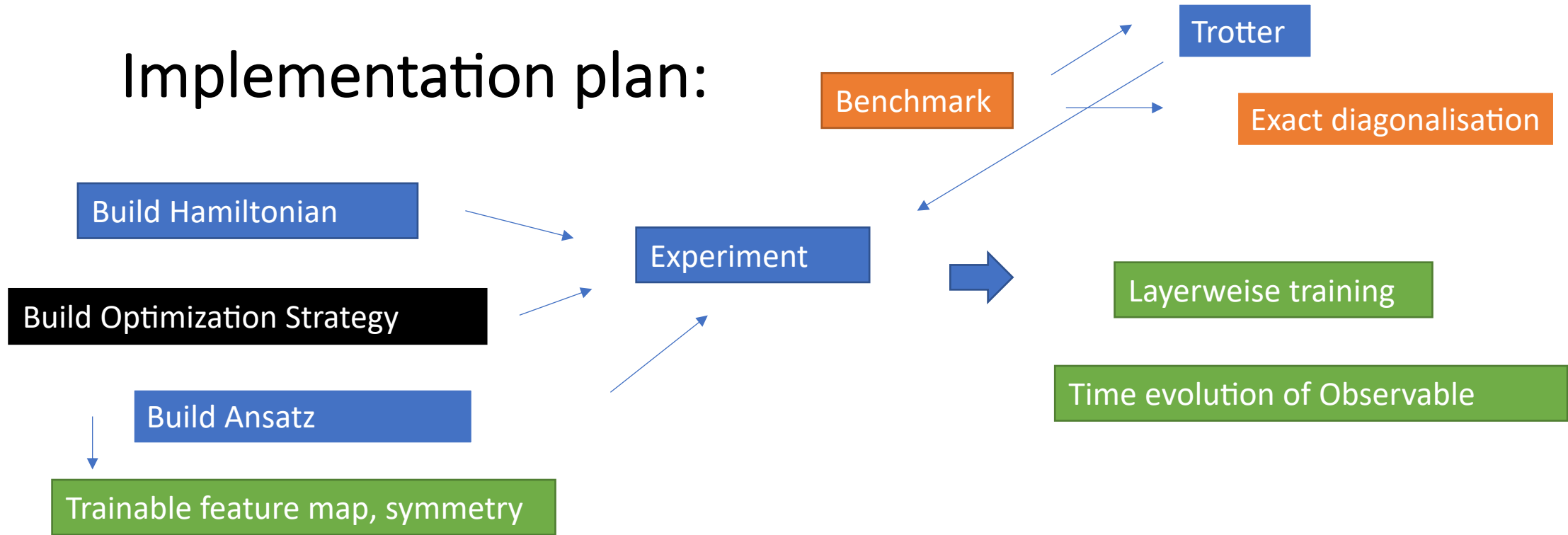
We will benchmark our results with classical strategy and Trotter evolution, both on simulator and harware.

**Impact:** Study Hamiltonian evolution more efficiently in the NISQ-era.

- Permits time evolution beyond the decoherence time.
- Uses less computational ressources than exact method, while being accurate.

[2] Andrea Skolik et al., *Layerwise learning for quantum neural networks*, Quantum Machine Intelligence 3 (2021).

# Implementation plan:



## Team:

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## Material:

- Qiskit machine learning
- Qiskit Aqua Operator
- Papers listed before