# Realization of variational quantum eigensolver on the polarization qubits

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The variational quantum eigensolver (VQE) method is used to find the eigenvalues of a given Hamiltonian $H$. VQE is a hybrid quantum-classical algorithm that performs classical optimization of a mean Hamiltonian value, which is found by a quantum hardware [2]. A classical computer sets a vector of parameters $\theta = \{\phi_1, \phi_2, \phi_3, \phi_4\}$, and an experimental setup prepares a quantum state $\psi(\theta)$ parameterized by these control parameters. After that the state is measured and the evaluation of the mean Hamiltonian value occurs. The parameters $\theta$ are adjusted to find the ground-state energy:

$$E_{\min}(\theta) = \min_{\theta} \left(\psi(\theta) H |\psi(\theta)\right).$$

Therefore, the problem consists in the selection of optimal angles $\theta$ corresponding to minimal value of energy by classical optimization algorithms.

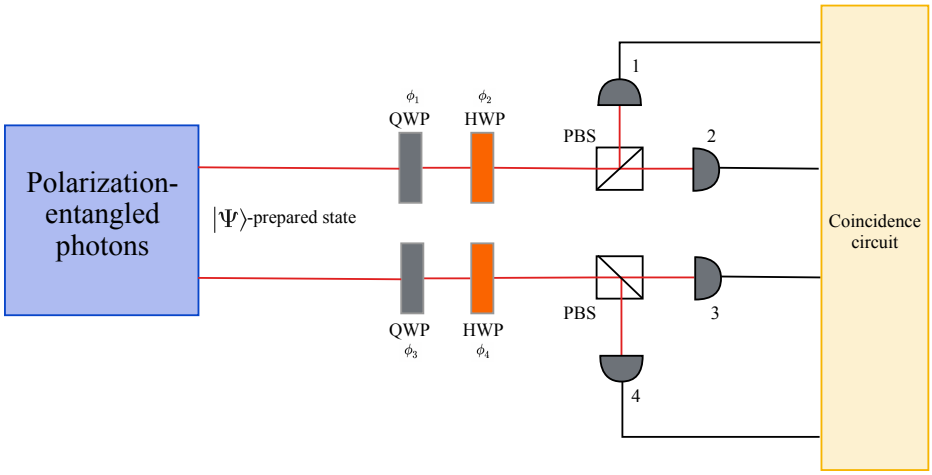


Figure 1: Experimental setup for execution of the variational quantum eigensolver algorithm using a pair of polarization qubits. A half-wave plate (HWP) and a quarter-wave plate (QWP) in each channel perform an arbitrary local unitary transformation and prepare the desired probe state $\psi(\theta)$. Polarizing beam splitters (PBS) implement projective measurements.

The scheme of the experimental setup is presented in fig. 1. Two-qubit states are generated by biphoton source using a polarization Sagnac interferometer [1]. Coincidence circuit registers coincidences between detectors $1-3$, $1-4$, $2-3$, $2-4$. Using these data, we calculate the ground state energy for the Hamiltonian $H = -Z_1 Z_2$. In the future, it is possible to implement other Ising-type Hamiltonians.

The result of the optimization is presented in fig. 2. We use Nelder — Mead algorithm to find a minimum. After some exploration of the parameter space the algorithm starts to converge to the ground-energy value, that is for $H = -Z_1 Z_2$ Hamiltonian is $E_{\min} = -1$.

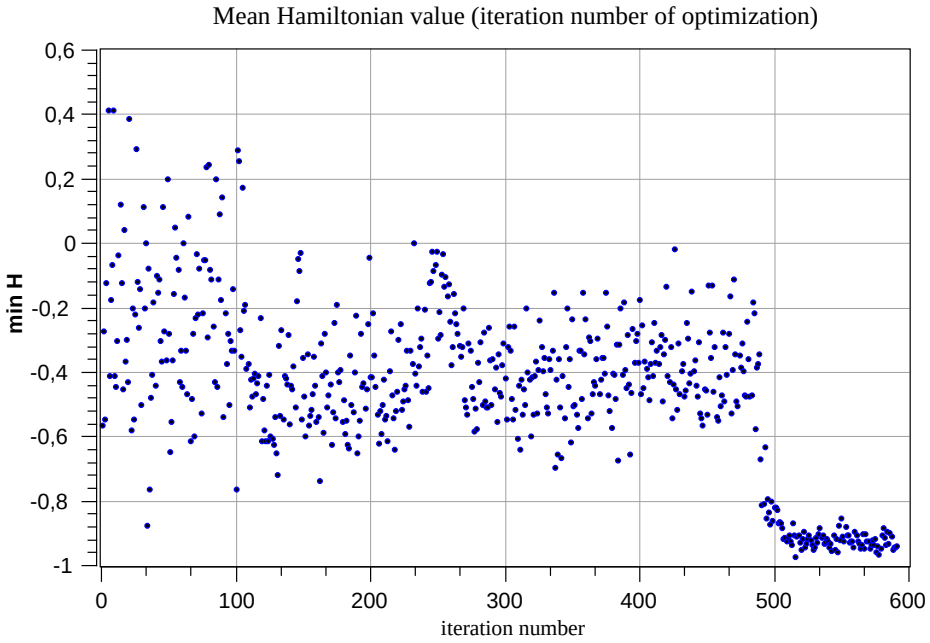


Figure 2: Mean value of $H = -Z_1 Z_2$ Hamiltonian as a function of iteration number for a Nelder — Mead classical optimization algorithm.

# References

[1] *Taehyun Kim, Marco Fiorentino, Franco N.C. Wong*, Phase-stable source of polarization-entangled photons using a polarization Sagnac interferometer, Phys. Rev. A **73**, 012316 (2006).

[2] *Nikolaj Moll et al*, Quantum optimization using variational algorithms on near-term quantum devices, Quantum Sci. Technol. **3**, 030503 (2018).