Jury Member Report – Doctor of Philosophy thesis.

Name of Candidate: Oksana Borzenkova

PhD Program: Computational and Data Science and Engineering

Title of Thesis: Linear optical realization of variational quantum algorithms

Supervisor: Professor Jacob Biamonte
Co-supervisor: Dr. Stanislav Straupe

Name of the Reviewer: Ivan Oseledets

I confirm the absence of any conflict of interest (Alternatively, Reviewer can formulate a possible conflict)	**Date: 01-12-2024**

The purpose of this report is to obtain an independent review from the members of PhD defense Jury before the thesis defense. The members of PhD defense Jury are asked to submit signed copy of the report at least 30 days prior the thesis defense. The Reviewers are asked to bring a copy of the completed report to the thesis defense and to discuss the contents of each report with each other before the thesis defense. *If the reviewers have any queries about the thesis which they wish to raise in advance, please contact the Chair of the Jury.*
Reviewer's Report

Here is a review of the doctoral thesis "LINEAR OPTICAL REALIZATION OF VARIATIONAL QUANTUM ALGORITHMS" by Oksana Borzenkova:

Summary of Main Results:
The thesis explores the implementation of variational quantum algorithms, specifically the Variational Quantum Eigensolver (VQE) and Quantum Approximate Optimization Algorithm (QAOA), on photonic quantum processors. The key results include:

1. Experimental demonstration of VQE on a free-space optical setup using polarization-encoded qubits to study the quantum phase transition in the Schwinger model. The results show that noise does not prevent the detection of the phase transition point across a broad range of noise levels, except for complete dephasing affecting both qubits.

2. Development and characterization of an integrated photonic quantum processor fabricated using femtosecond laser writing in fused silica. This processor is used to estimate the bound energy of the H2 molecule via a VQE experiment.

3. Application of the zero-noise extrapolation (ZNE) method to mitigate partial photon distinguishability in the linear-optical quantum processor. ZNE significantly improved the accuracy of ground energy estimates beyond the constraints imposed by photon distinguishability.

Novelty and Contributions:
The thesis makes several novel contributions to the field of quantum computing and photonic quantum information processing:

1. Experimental demonstration of the noise-tolerance of variational quantum algorithms in identifying quantum phase transitions, providing insights into the robustness of these algorithms on NISQ devices.

2. Design and fabrication of a reconfigurable integrated photonic quantum processor, which represents a significant advancement in the complexity and performance of femtosecond laser-written quantum devices.

3. Application of the ZNE error mitigation technique to linear-optical quantum processors, showing its effectiveness in improving the accuracy of VQE results beyond the intrinsic limitations of the hardware.

Overall Structure:

The thesis is structured in a logical and coherent manner. It begins with an introduction to quantum algorithms, particularly variational approaches, and provides a review of the relevant literature on physical implementations of quantum processors and the application of variational algorithms. The subsequent chapters delve into the experimental work, covering the noise-resilience study, the integrated photonic processor development, and the ZNE error mitigation technique. The thesis concludes with a discussion of multi-photon sources and a summary of the key findings.

3. The inclusion of a section or chapter dedicated to the theoretical underpinnings of the variational quantum algorithms and their relation to the specific physical implementation could further strengthen the thesis.

Comments:
1. The thesis could benefit from a more in-depth discussion of the limitations and challenges encountered in the experimental work, as well as potential avenues for future improvements and scalability of the photonic quantum processor.

2. While the thesis demonstrates the effectiveness of the ZNE method, a more comprehensive analysis of the trade-offs between the improved accuracy and the increased experiment duration or estimator variance would provide a more complete picture of the method's practical applicability.

3. ZNE method focuses on linear extrapolation; in numerical analysis, this reminds me of so-called 'Richardson extrapolation' which approximates the solution of a partial differential equation (PDE) given on different grids, but the assumption is more general: f(h) = f0 + O(h^c). Are there any models that have non-linear dependence on the noise level?
3. It would be interesting to highlight personal contribution of the author, for example, for the experimental setup.

Conclusion:
I think, the work of Oksana provides interesting results and makes a significant contribution to the field.

Provisional Recommendation
I recommend that the candidate should defend the thesis by means of a formal thesis defense
I recommend that the candidate should defend the thesis by means of a formal thesis defense only after appropriate changes would be introduced in candidate's thesis according to the recommendations of the present report
The thesis is not acceptable and I recommend that the candidate be exempt from the formal thesis defense