（別紙様式５）

変革を駆動する先端物理・数学プログラム（FoPM）

国外連携機関長期研修　報告書

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日程	西暦　2025　年　4　月　10　日　～　西暦　2025　年　6　月　28　日

1. Motivation for Participation

The primary motivation behind my participation in this overseas research training program was to broaden my research perspective by engaging with a new area of quantum information science. At my home university in Japan, I have been conducting research on photonic continuous-variable systems, where quantum states are described as superpositions over real numbers. However, I was also interested in exploring a different framework—namely, photonic qubit systems—and sought to deepen my understanding of discrete-variable approaches.

The Philip Walther group, which I joined for this program, is an internationally recognized research group specializing in photonic qubits, particularly in experimental quantum information processing based on photonics. In this environment, I worked on basic research involving time-bin qubits.

By working with discrete-variable systems, I aimed to experience experimental challenges and techniques that differ from those in continuous-variable systems. This opportunity was highly motivating for me, as I believed it would allow me to learn new approaches and perspectives that could enrich my own research going forward.

2. Research Activities

During the training, I was involved in both theoretical and experimental aspects of time-bin qubit research. My work consisted of two main projects:

(1) Theoretical Study: Investigation of a Specific Quantum State Tomography Method for Time-Bin Qubits

As part of my research, I conducted a theoretical investigation into one specific type of quantum state tomography (QST) method for time-bin qubits. In time-bin qubits, quantum information is encoded in two distinct temporal modes, known as the early (|e⟩) and late (|l⟩) time bins. The QST method I focused on utilizes interference effects between these temporal modes to reconstruct the quantum state.

I examined whether this method could successfully reconstruct the density matrix of a quantum state. Through this investigation, I gained a deeper understanding of the measurement characteristics unique to time-bin qubits and the challenges involved in their quantum state reconstruction. I also had valuable discussions with local researchers, which helped me refine my understanding of the theoretical models and experimental feasibility.

(2) Experimental Work: Construction of a Time-Bin Qubit Generator

In parallel with my theoretical work, I contributed to the experimental setup of a time-bin qubit generator. A time-bin qubit is defined as a superposition of the early |e⟩ and late |l⟩ time bins. Such qubits can be generated by constructing an unbalanced Mach-Zehnder interferometer, in which the two arms have different lengths.

I constructed an unbalanced Mach-Zehnder interferometer that interferes light traveling along a short path and a long path. The interference signal was detected by a photodetector, and I performed a test to lock the interferometer at a certain point using PID control.

Participating in the construction of this generator gave me practical skills in photonics engineering and quantum optics. I also gained insight into how theoretical designs are translated into working experimental systems, which will be valuable for my future research.



Fig.1 The actual experimental setup.

3. Daily Life and Cultural Experiences

Beyond the research, my time abroad provided me with countless opportunities for personal growth and cultural enrichment. On weekends and holidays, I traveled extensively across Europe, visiting 12 cities in 9 different countries. This included historically and culturally significant destinations such as Vienna, Salzburg, Hallstatt, Budapest, Prague, Bratislava, Rome, Venice, Paris, London, Vatican City, and Barcelona.

During these trips, I explored famous landmarks, museums, and historical sites. I learned about the diverse histories, architectures, and traditions of each city. Visiting locations like the Colosseum in Rome, the Eiffel Tower in Paris, and Schönbrunn Palace in Vienna left a deep impression on me. I also had the chance to interact with local people, experience different cuisines, and observe various lifestyles.

These travel experiences significantly broadened my worldview and taught me the importance of understanding and respecting cultural diversity. I strongly believe that such international exposure will help me become a more open-minded researcher capable of collaborating with scientists from around the globe.

4. Outcomes and Reflections

This overseas research training program was an extremely valuable experience for me. I achieved the following key outcomes:

・Acquired theoretical knowledge about quantum state tomography methods applicable to time-bin qubits.

・Gained hands-on experience in constructing a time-bin qubit generator.

・Improved my experimental skills in quantum optics and photonics, including optics alignment and interferometer stabilization.

・Expanded my cultural horizons by traveling across Europe and immersing myself in diverse environments.

・Strengthened my communication skills by working in an international research environment where English was the primary language of communication.

Working in a laboratory with members from different countries made me realize the importance of clear and precise communication, especially when discussing complex scientific concepts. This experience encouraged me to improve my ability to convey ideas effectively in English.

I am confident that the knowledge and skills I gained through this program will greatly contribute to my future research activities in the field of quantum information science. Furthermore, the cultural experiences I had will continue to inspire me as I pursue international collaborations in the future. I hope to maintain the connections I built during this training and to develop joint research projects in the coming years.