

PhD Thesis Defense: Experimental demonstrations of quantum repeater nodes and links with photon pair sources and multimode quantum memories

JONATHAN ROMAN LOUIS HANNI

December 11, 2026

10:30

ICFO Auditorium

Quantum networks aim to distribute quantum states between distant nodes, enabling applications such as quantum key distribution, distributed quantum computing, and quantum sensing. Optical loss in optical fiber, however, is a roadblock to the realization of fiber-based quantum networks at a continental scale. A promising work-around relies on quantum repeaters, where entanglement is generated, stored and distributed between remote locations in a heralded fashion. In this thesis, we focus on a notable approach based

on photon-pair sources coupled to multimode quantum memories, forming network compliant quantum nodes. Among various requirements for network operations, we highlight compatibility with the existing fiber network, high system efficiency, long memory storage time and large access to multiplexing. In this thesis, we use photon-pair sources based on cavity-enhanced spontaneous parametric down-conversion coupled to solid-state absorptive quantum memories based on rare-earth-doped solids (specifically, we use Pr:YSO) to perform basic demonstrations of quantum repeater links and nodes. We showcase the viability of this platform with regards to the aforementioned requirements.

We start in Chapter 3 by demonstrating heralded entanglement of two spatially separated on-demand spin-wave solid-state quantum memories. We also implement fast conditional phase-control of the heralded entangled state to double the heralding rate up to 510 1/s. Furthermore, we illustrate the linear advantage of temporal multiplexing by implementing an unconditional storage scheme emulating the operation of a metropolitan-distance link. These results are made possible by the state-of-the-art signal-to-noise ratio of the heralded single photon storage as well as the delicate phase stabilization necessary for consistent heralding and entanglement certification.

In Chapter 4, a new generation of photon-pair source is designed, based on a periodically-poled potassium titanyl phosphate nonlinear crystal. Two replicas of the new design are assembled, characterized and compared to the older generation based on periodically-poled lithium niobate. We achieve a heralding efficiency above 0.5 with both setups, more than a factor 2 improvement from the previous generation. The heralded single-photon linewidth is measured below MHz level for both replicas. Additionally, the spectral structure of emission, the response to pump power and other figures of merit are measured through time and frequency resolved measurements.

We further showcase the extensive capabilities of our quantum node system in Chapter 5 by coupling our photon-pair sources to various high-performance quantum memory demonstrators. Specifically, we firstly demonstrate long-lived heralded single-photon storage in our quantum memory through the use of spin-rephasing techniques, preserving non-classical correlations after a total storage time beyond 10 us. Secondly, we report heralded single-photon storage in a cavity-enhanced high-efficiency memory. We report storage in the excited state at an efficiency up to 0.306(18) and storage as a spin-wave at an efficiency of 0.182(14) whilst preserving non-classical correlations in both cases. Lastly, a final experiment is performed, storing heralded single photons in a quantum memory array featuring 10 independent spatial modes, each featuring 6 temporal modes. We measure non-classical correlations after storage across all 10 spatial modes. We then harness the telecom compatibility given by the photon-pair source to propagate the non-classical correlations over a 39.1 km deployed fiber link in the metropolitan area of Barcelona.

The work presented in this thesis marks a sizable step towards more advanced demonstrations of quantum repeater links, and ultimately, a practical and scalable quantum

repeater based on photon-pair sources coupled to multimode quantum memories.

Friday December 11, 10:30 h. ICFO Auditorium

Thesis Director: Prof. Dr. Hugues De Riedmatten and Dr. Samuele Grandi

Hosted by: Prof. Dr. Hugues de Riedmatten