# Quantum Correlations in Fiber Links of the Recife Quantum Network

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***Abstract.*** *This work presents the experimental characterization of quantum correlations in optical fiber links of the Recife Quantum Network using a type-II SPDC photon-pair source operating at 800 nm. The analysis is based on the normalized cross-correlation function $g_{12}^{(2)}$, used to quantify temporal correlations between signal and idler photons. One photon of each pair is transmitted through the network in a loop configuration, while its partner is detected locally. The results show that quantum correlations are preserved after propagation through urban optical fibers, despite attenuation and environmental noise. These findings demonstrate the potential of the infrastructure for quantum communication experiments, including quantum key distribution (QKD), in urban-scale networks.*

## 1. Introduction

Quantum technologies have become a central area of contemporary science, with important implications for secure communications, quantum information processing, and distributed computational architectures [Gisin and Thew 2007] [Kimble 2008] [Wehner et al. 2018]. In particular, the use of quantum states of light, especially entangled photons, provides a powerful framework for encoding and transmitting information in ways that have no classical counterpart. This capability underpins applications such as quantum key distribution (QKD) and motivates the development of quantum networks designed to interconnect remote quantum nodes and processing platforms [Pirandola et al. 2020] [Covey et al. 2023].

Over the last two decades, quantum communication has progressed from predominantly theoretical proposals to a broad range of experimental realizations and network-oriented implementations [Kimble 2008] [Wehner et al. 2018] [Martin et al. 2024] QKD infrastructures are already being deployed and operated in several regions, including

China, Europe, Japan, and the United States, reflecting the growing interest in secure communication technologies driven by increasingly complex cybersecurity challenges and the prospective impact of quantum computing on conventional cryptographic schemes [Chen et al. 2025] [Pirandola et al. 2020] [Jain et al. 2022]. In Brazil, however, this field is still developing, with recent efforts focused on establishing the experimental and technological foundations required for scalable quantum communication platforms.

In this context, this work presents the experimental foundation of a pioneering Brazilian initiative aimed at developing an urban quantum network interconnecting four laboratories in the city of Recife.

## 2. SPDC Source

The photon-pair source considered here is a QWeb prototype operating in a single-pass crystal configuration, pumped by a continuous-wave (CW) diode laser with a central wavelength of 405 nm. In this setup, the pump beam is focused onto a 10-mm-long PPKTP crystal, designed for collinear type-II SPDC generation.

he SPDC process occurs when a pump photon, with wavelength, $\lambda_p$, interacts with the nonlinear crystal and is converted into two lower-energy photons, referred to as the signal and idler photons. Figure 1 shows the experimental setup of the source. After photon-pair generation, a spectral filter is used to block the residual pump beam, allowing only the SPDC photons to propagate. The photons are then separated according to their horizontal and vertical polarizations using a PBS. After separation, the photons are coupled into optical fibers that guide them to detectors D1 and D2, as indicated in Fig. 1.

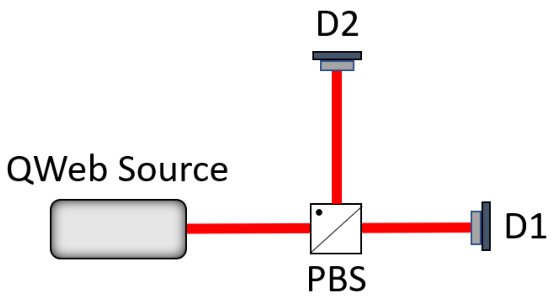


**Figure 1. Experimental setup used for the generation and analysis of photon pairs via type-II SPDC. The SPDC photons are separated at the PBS and collected by fiber couplers D1 and D2, which direct them to the APDs.**

In this work, temporal quantum correlations between the photons are characterized through the normalized second-order cross-correlation function $g_{12}^{(2)}$, defined as $g_{12}^{(2)} = C/A$, where $C$ and $A$ denote the coincidence peak and the accidental background counts measured over an equivalent temporal window. The coincidence-to-accidental ratio (CAR), defined as $\mathrm{CAR} = C/A - 1$, is directly related to $g_{12}^{(2)}$ and approaches it for large values of the correlation (for further details, see [Oliveira et al. 2025]).

The source was experimentally characterized under local laboratory conditions, i.e., without propagation through the network. The measured singles rates were approximately $1.0$ MHz and $0.5$ MHz in the reflection and transmission arms, respectively, with a coincidence rate of about $43$ kHz. Using a coincidence window of $1$ ns and an experimentally measured accidental background of $370$ Hz, we obtain a coincidence-to-accidental ratio of $\mathrm{CAR} \approx 115$, indicating strong temporal correlations between the photon pairs.

These values provide a quantitative baseline for the source performance in the local configuration and serve as a reference for evaluating the degradation of quantum correlations after propagation through the fiber links.

## 3. Quantum Network in Recife

The Recife Quantum Network (RQN) project aims to establish quantum communication links over urban-scale optical fiber infrastructure. The current network configuration, illustrated in Figure 2, interconnects multiple nodes within the metropolitan area of Recife through deployed fiber links. To evaluate the feasibility of distributing quantum correlations across this infrastructure, we performed an experimental study based on the propagation of one photon from each SPDC-generated pair through the network, as shown in Figure 3.

In this configuration, one photon is transmitted through the fiber links in a loop arrangement, reaching remote nodes and returning to the laboratory, while its correlated partner is detected locally. This approach allows for controlled investigation of propagation effects, such as attenuation and noise, while preserving a well-defined temporal reference between detection events. The total propagation distances considered in this work range up to $4.5$ km, enabling the assessment of quantum correlations under realistic urban network conditions.


**Figure 2. Current configuration of the RQN, interconnecting three main sites. At UFPE, the network links the Department of Physics (EQL laboratory at CCEN) to the Department of Electronics and Systems (CTG), while at UFRPE the connected site is the Department of Physics (LOL). Solid lines represent the optical fiber links that are already installed and operational, whereas the dashed line indicates the planned connection to QUANTA-UFPE, which is presently being implemented as part of the first expansion phase.**

The impact of fiber propagation on the detected signals was characterized by measuring the singles rates, coincidence counts, and accidental background as a function of the propagation distance. All measurements were performed using a pump power of $1$ mW at $405$ nm. While the singles rate in the local detection arm remained approximately constant at $500$ kHz, the singles rate in the transmitted arm decreased significantly with increasing fiber length, from about $1.0$ MHz in the local configuration to $70$ kHz, $25$ kHz, and $8$ kHz for propagation distances of $1.5$ km, $3.0$ km, and $4.5$ km, respectively.

A corresponding reduction was observed in the coincidence rate, which decreased from approximately $43$ kHz in the local configuration to $2.5$ kHz, $825$ Hz, and $230$ Hz for the same distances. The accidental coincidence rate also decreased with distance, with measured values of $370$ Hz, $31$ Hz, $14$ Hz, and $3$ Hz, reflecting the reduction in uncorrelated detection events due to attenuation in the transmitted arm.

These results demonstrate that fiber losses primarily affect the transmitted photon, leading to a strong reduction in both singles and coincidence rates, while the reference arm remains stable. This asymmetry provides a clear indication that the degradation of the measured correlations is dominated by propagation effects in the optical fiber links.

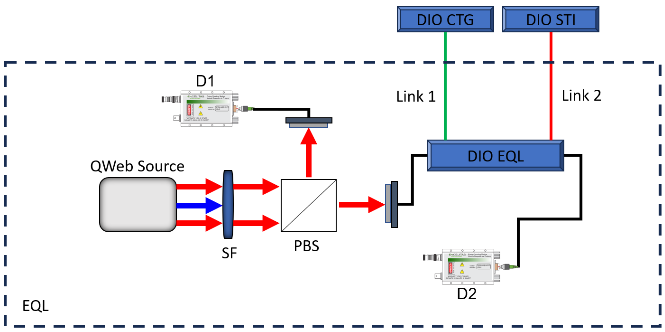


**Figure 3. Experimental arrangement used to evaluate the preservation of quantum correlations in the optical fiber infrastructure of the RQN. In this configuration, one photon from each SPDC-generated pair is transmitted through an optical loop to a remote node, either CTG or STI, and subsequently returned to the EQL-UFPE laboratory. The SPDC source remains the same as that shown in Fig. 1; however, in this case, the photon transmitted through the PBS propagates through the network via Link 1 and/or Link 2 before returning to the laboratory. The corresponding total round-trip distances for Link 1 and Link 2 are approximately 1.4 km and 3 km, respectively [Oliveira et al. 2025].**

The preservation of temporal quantum correlations after propagation through the fiber links was evaluated using the normalized second-order cross-correlation function $g_{12}^{(2)}$, as defined in Section 2. The measured values of $g_{12}^{(2)}$ as a function of the fiber length are shown in Figure 4.

For the local configuration, we obtain $g_{12}^{(2)} = 115$, while for propagation distances of $1.5$ km, $3.0$ km, and $4.5$ km, the measured values are $73.7$, $72.4$, and $62.4$, respectively. Although a gradual decrease in $g_{12}^{(2)}$ is observed with increasing distance, all values remain significantly above unity, indicating the persistence of strong temporal correlations between the photon pairs after transmission through the network.

The observed behavior of the accidental coincidence rate is consistent with the expected scaling $A \approx S_1 S_2 \tau$, where $S_1$ and $S_2$ are the singles rates in each detection arm and $\tau$ is the coincidence time window. As the propagation distance increases, the singles rate in the transmitted arm decreases due to fiber attenuation, leading to a corresponding reduction in the accidental coincidence rate. This trend is in agreement with

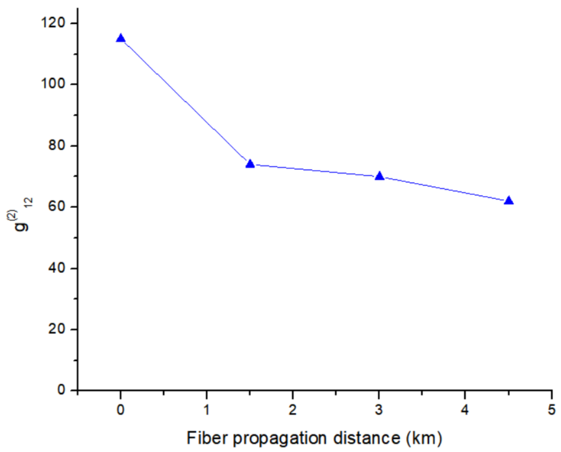


**Figure 4. Measured second-order cross-correlation function $g^{(2)}_{12}$ as a function of the optical fiber length. A gradual decrease in $g^{(2)}_{12}$ is observed with increasing distance due to attenuation in the fiber, which reduces the coincidence rate. Despite this degradation, all measured values remain significantly above unity, indicating the preservation of temporal quantum correlations after propagation through the network.**

the experimental data and supports the interpretation that the degradation of the measured correlations is primarily governed by propagation losses in the optical fiber.

## 4. Conclusions and perspectives

This work presents the first experimental characterization of the QWEB photon-pair source within the RQN. The analysis, based on the normalized cross-correlation function $g^{(2)}_{12}$, shows that temporal quantum correlations are preserved after propagation through urban optical fiber links, despite significant attenuation. This metric, widely used in quantum optics and atomic ensemble experiments, provides a simple and robust measure of photon correlations suitable for initial system validation [Araújo et al. 2022].

Operation at $800\ \mathrm{nm}$, although not optimal for telecom fibers, was adopted due to practical and budgetary constraints, enabling a first validation of the network infrastructure under realistic conditions.

## 5. Acknowledgements

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## References

Araújo, M. O., Marinho, L. S., and Felinto, D. (2022). Observation of nonclassical correlations in biphotons generated from an ensemble of pure two-level atoms. *Phys. Rev. Lett.*, 128:083601.

Chen, H. Z. et al. (2025). Implementation of carrier-grade quantum communication over china's existing fibre-optic communication infrastructure. *npj Quantum Information*, 11:11.

Covey, J. P., Bernien, H., Zibrov, A. S., and Lukin, M. D. (2023). Quantum networks with neutral atom processing nodes. *npj Quantum Information*, 9:74.

Gisin, N. and Thew, R. (2007). Quantum communication. *Nature Photonics*, 1(3):165–171.

Jain, N., Jensen, H. H., Gehring, T., and Andersen, U. L. (2022). Practical continuous-variable quantum key distribution with composable security. *Nature Communications*, 13:4740.

Kimble, H. J. (2008). The quantum internet. *Nature*, 453(7198):1023–1030.

Martin, V. et al. (2024). Madqci: a heterogeneous and scalable sdn-qkd testbed for quantum communication integration in optical networks. *npj Quantum Information*, 10:62.

Oliveira, N. W. S., Siqueira, A. C. A., Crisóstomo, G. A., Martins, P., Freitas, L. L. L., de Almeida, A. A. C., Acioli, L. H., Martins-Filho, J. F., Coelho, L. D., Ferraz, J., and Felinto, D. (2025). Photon-pair source for the recife quantum network. *Brazilian Journal of Physics*, 56(2):58.

Pirandola, S., Andersen, U. L., Banchi, L., Berta, M., Bunandar, D., Colbeck, R., Englund, D., Gehring, T., Lupo, C., Ottaviani, C., Pereira, J. L., Razavi, M., Shaari, J. S., Tomamichel, M., Usenko, V. C., Vallone, G., Villoresi, P., and Wallden, P. (2020). Advances in quantum cryptography. *Advances in Optics and Photonics*, 12(4):1012–1236.

Wehner, S., Elkouss, D., and Hanson, R. (2018). Quantum internet: A vision for the road ahead. *Science*, 362(6412):eaam9288.