Resources and applications for advanced quantum networking

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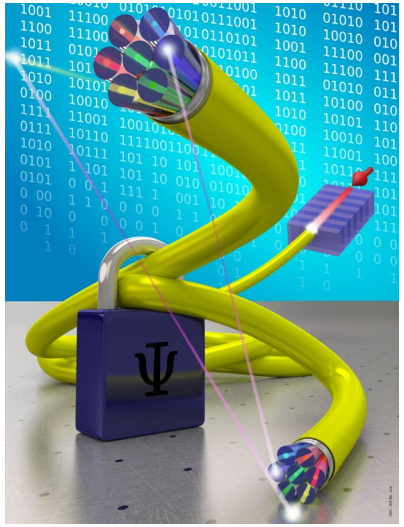
Paris Centre for Quantum Technologies

Kaleidoscope Conference, Geneva, Switzerland

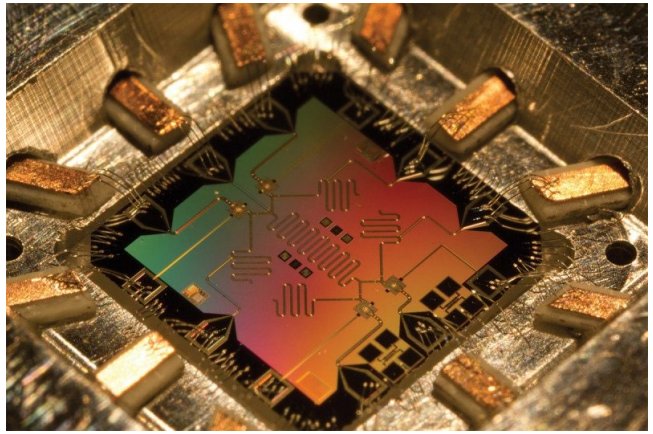
9 July 2026

Quantum technologies

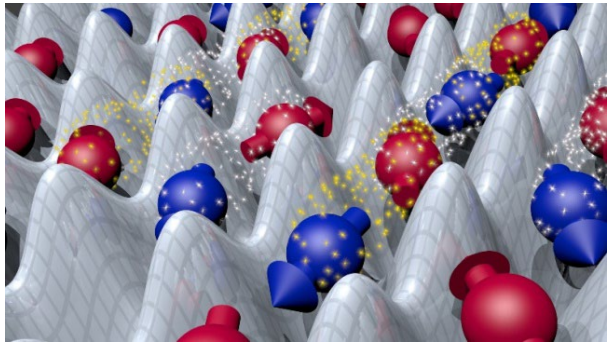
Unconditionally secure communication



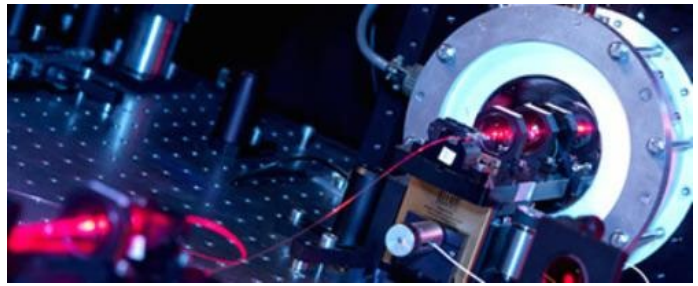
A leap in computing power



Increased understanding of complex physical systems

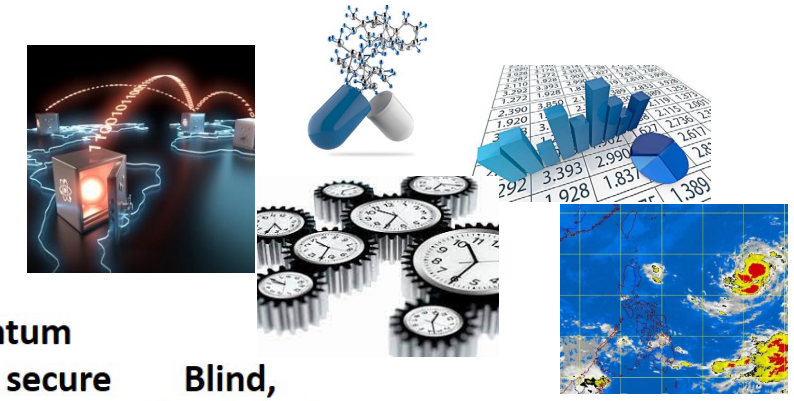


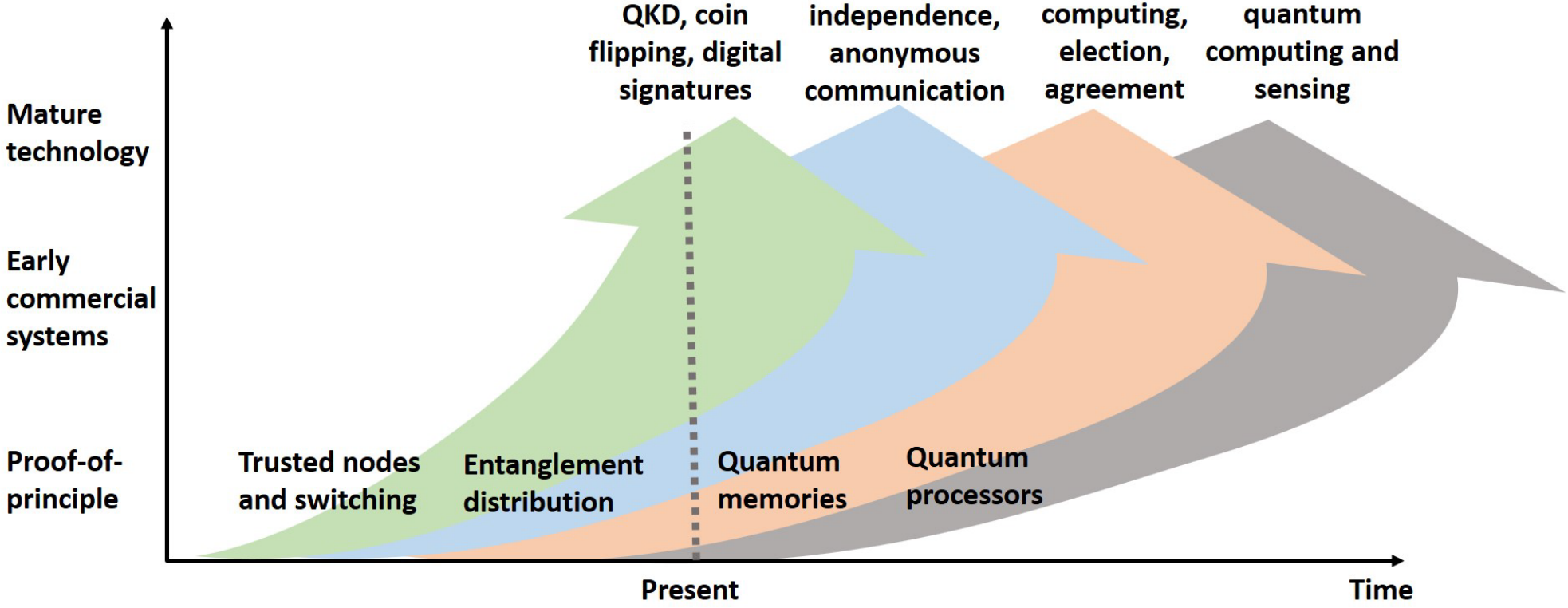
Measurement precision beyond the classical limit



Quantum communication network stages and applications

Quantum communication is the art of transferring quantum information between distant locations





E. Agrell *et al.*, *Roadmap on Optical Communications*, J. Opt. 26, 093001 (2024)

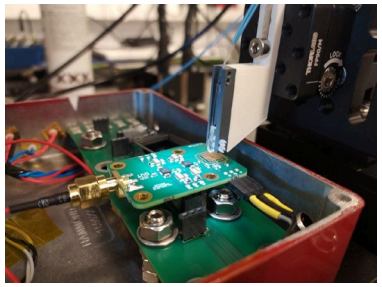
Quantum secure networks

Quantum Key Distribution (QKD) offers a fundamental functionality and has a pilot role in the TRL ladder for quantum networks

Ongoing efforts aim at demonstrating that technology can work:

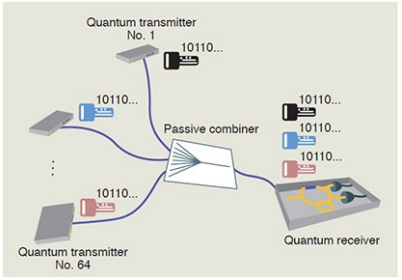
at large scale

cost-effective & small form factor



over real-world networks

coexistence & key management



for real-world security

QKD+Post-Quantum Cryptography hybridization ensuring defense-in-depth for resilient, quantum-safe communication & hardware evaluation

with minimal trust assumptions

(semi) device independence

Demonstrate compelling functionalities beyond QKD with provable quantum advantage:

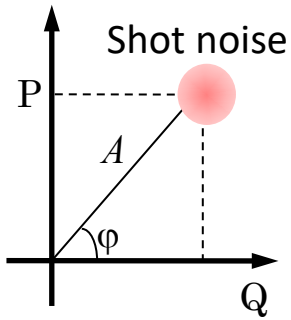
Secure multi-party computation

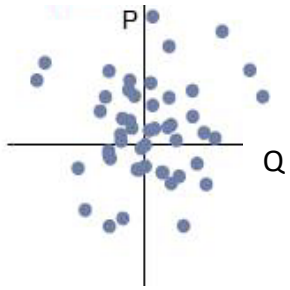
Long-term secure storage

Unforgeable quantum money

Secure distributed quantum sensing

Coherent-state continuous-variable QKD

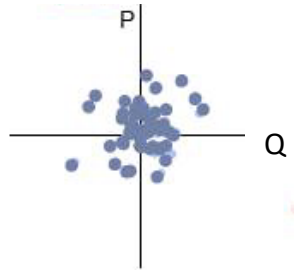




$$\{q_i \quad p_i, 1 \le i \le N\}$$

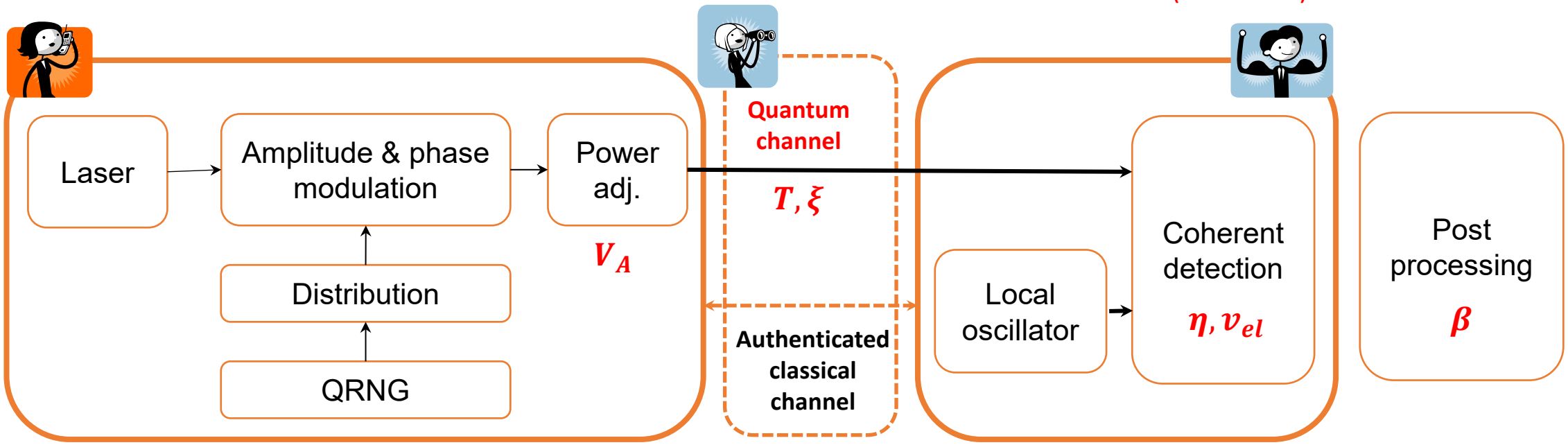
$$|\alpha\rangle_i = |q_i + ip_i\rangle$$

Continuous (Gaussian) or discrete (QPSK, QAM,…)



Single (homodyne) or double (heterodyne) quadrature detection

Trusted (calibrated) noise

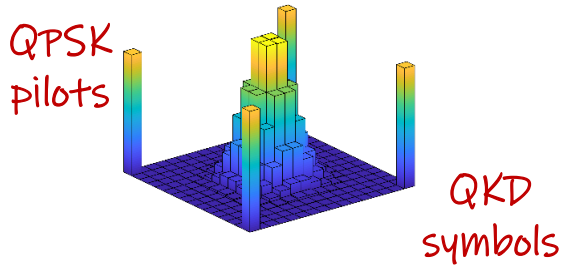


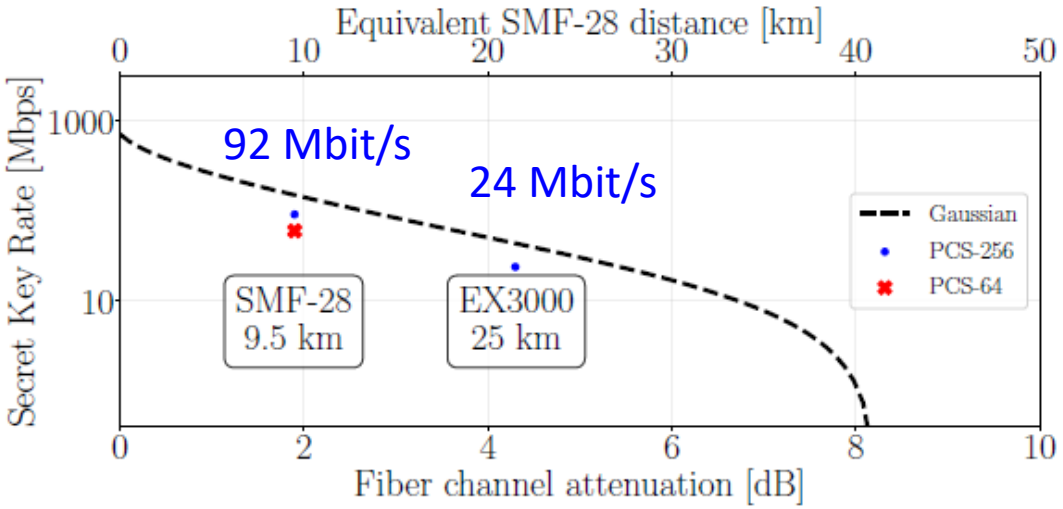
Alice and Bob perform noise variance measurements to bound the Holevo information of Eve:

$$K = \beta I_{AB}(V_A, T, \xi, \eta, v_{el}) - \chi_{BE}(V_A, T, \xi, \eta, v_{el})$$

Highly-integrated Continuous-Variable QKD

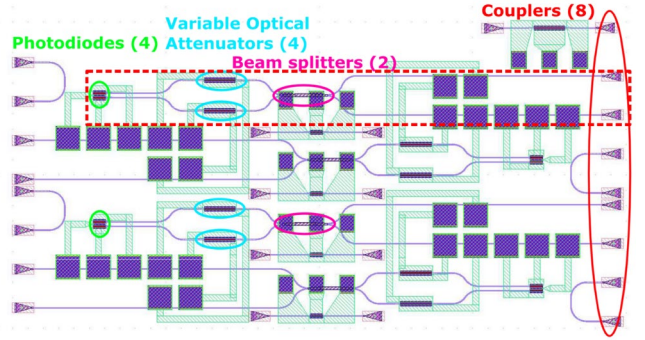
Leverage compatibility with technology and digital signal processing (DSP) techniques used in coherent telecom systems





Home made open source modular software
https://github.com/qosst/qosst

Photonic integrated circuits for CV-QKD transmitter on InP and receiver on Si



Y. Piétri *et al.*, Optica Quantum 2024
J. Aldama *et al.*, Opt. Express 2025

Side-channel attacks and functional tests
Contributing to certification efforts

NSTRADAMUS

F. Roumestan *et al.*, J. Lightwave Technol. 2024 & Y. Piétri *et al.*, Quantum 2024

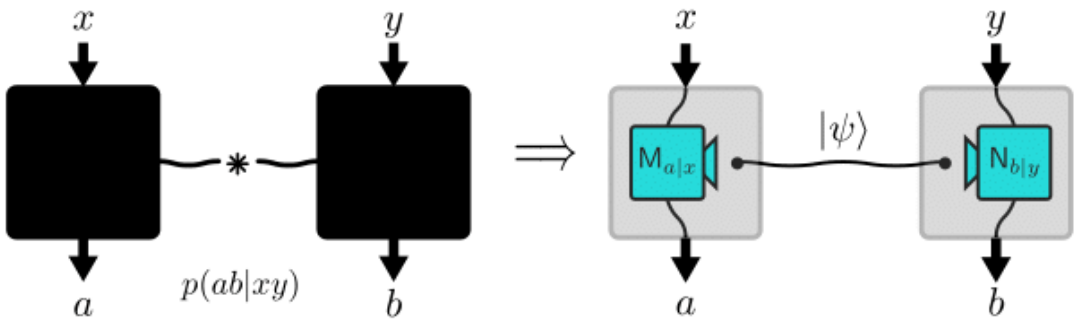
Certification of multipartite entangled states

The development of tools to certify the "**quantumness**" of resources is fundamental for practical applications

Multipartite entangled states are a crucial resource for quantum network protocols
To guarantee protocol properties - privacy, security, anonymity,…, introduce subroutine for authentication of the resource

Ideally no assumptions for certification: black box model → device independence (DI)

Violation of Bell inequality is a DI witness of entanglement
→ ***maximal*** Bell violation DI witness of ***particular*** quantum states and measurements?

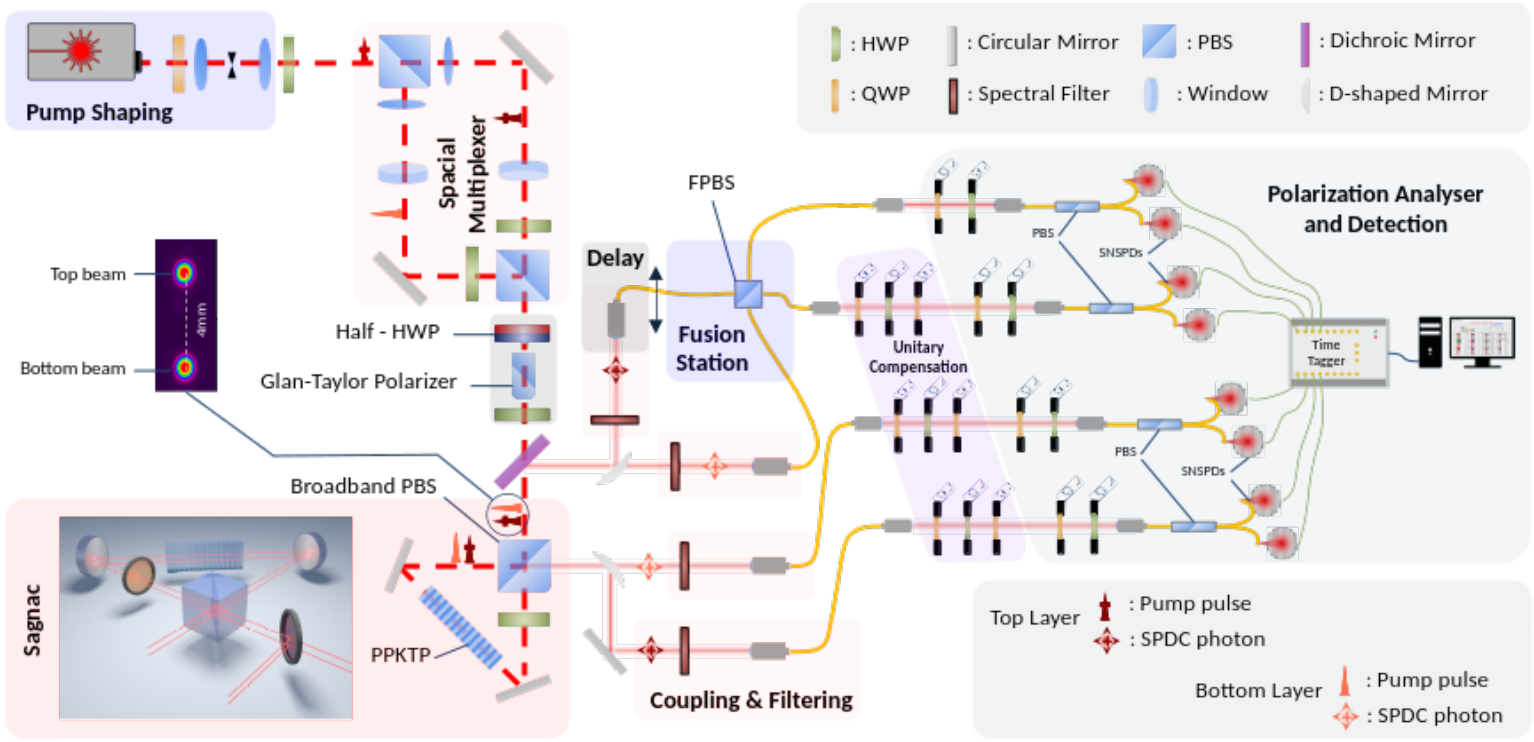


Self-testing: the distance of the observed violation from the maximal one bounds the fidelity of the state

Typically, important assumptions:
no losses, large sets of independently and identically distributed (IID) states, measurement of all states,…

I. Šupić and J. Bowles, *Self-testing of Quantum Systems: A Review*, Quantum 2020

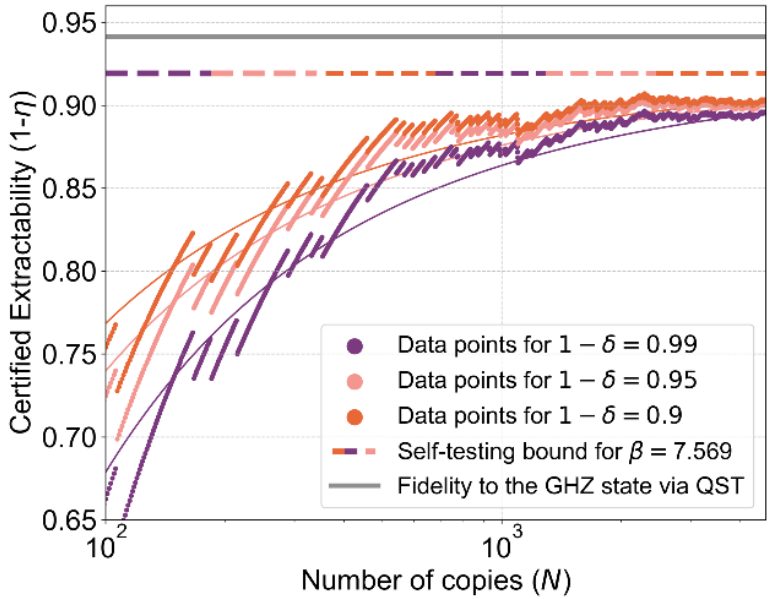
Experimental GHZ state certification



$$|\mathrm{GHZ}\rangle = \frac{1}{\sqrt{2}}(|HHHH\rangle + |VVVV\rangle)$$

F = 96.88 %

Few-copies, non-IID certification
Certified state preserved



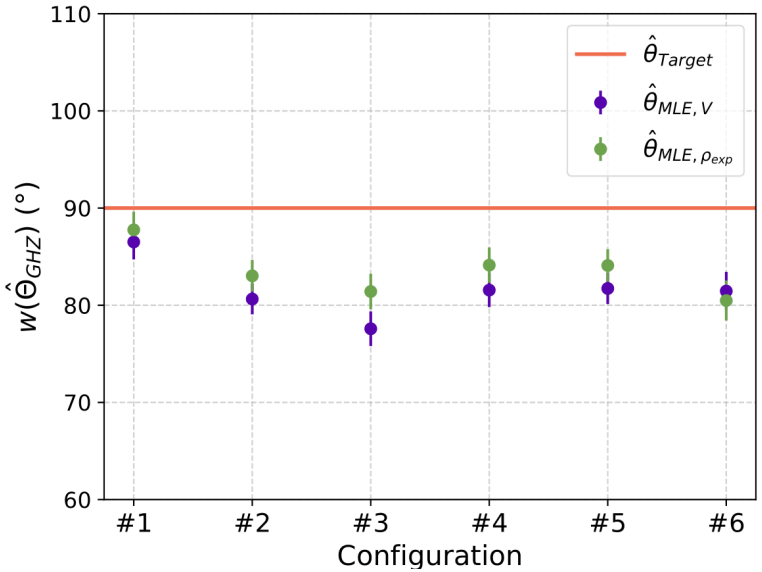
Certification of $\Xi(\sigma_c, |GHZ\rangle) \geq 0.896$
for $1 - \delta = 0.99$ and $N = 4643$

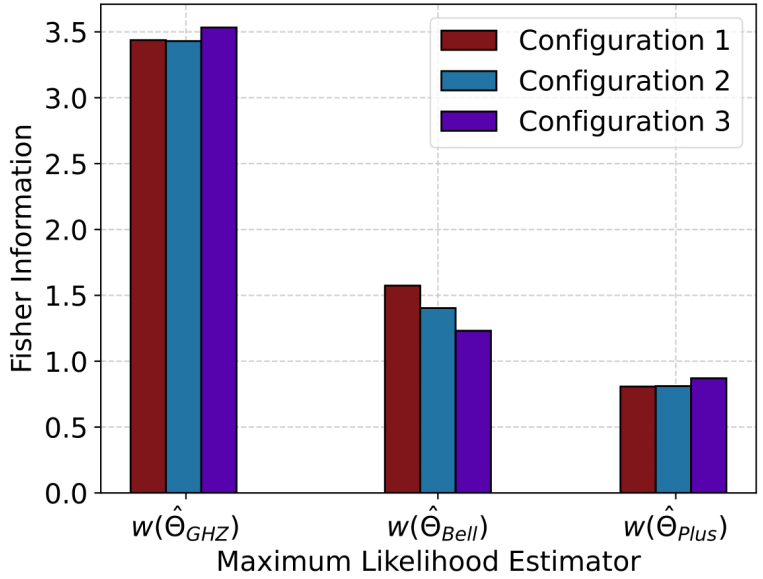
L. dos Santos Martins *et al.*, Opt. Express 2025 & Science Advances 2026

Application to private distributed quantum sensing

Application of multipartite entanglement DI certification techniques
to privacy-preserving phase estimation in distributed networks of sensors

Estimate a linear function $f(\Theta) = a^T \cdot \Theta$.
No other information other than $f(\Theta)$ is revealed.





Good accuracy for estimation of global phase for optimal number of rounds
Maximal Fisher information for GHZ states

Similar techniques also applied to quantum e-voting without a central authority

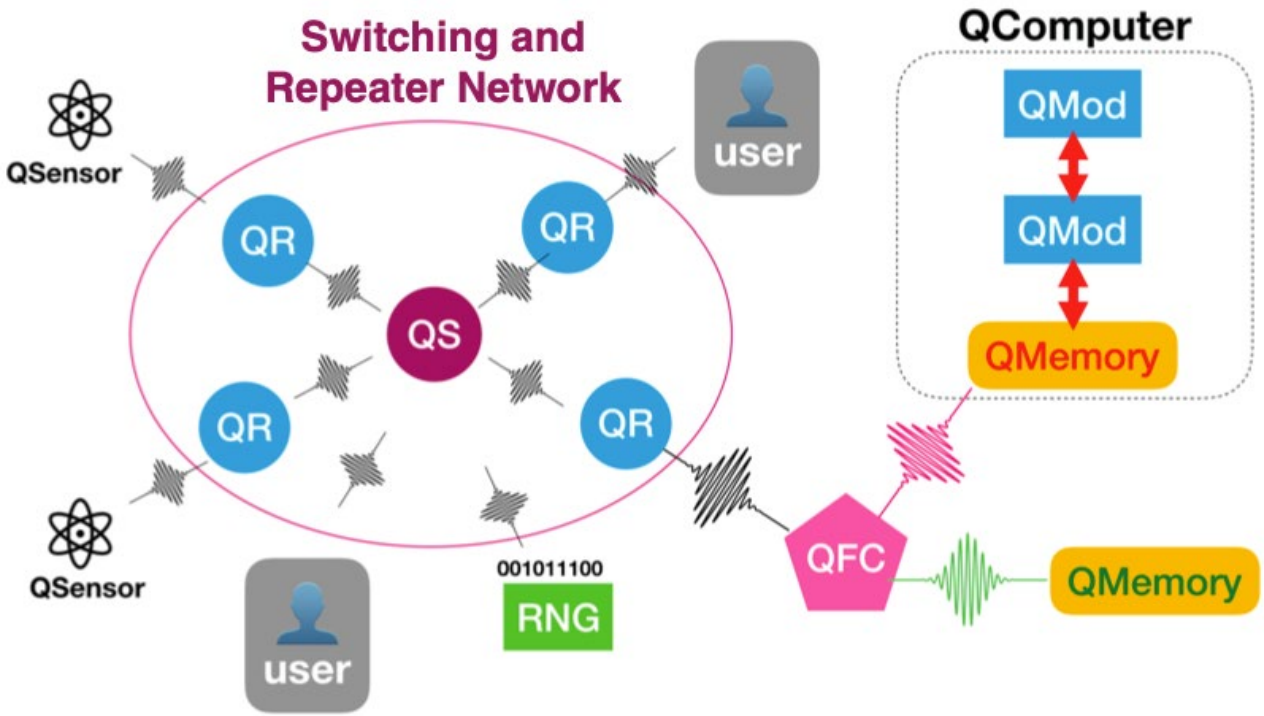
N. Laurent-Puig *et al.*, QCrypt 2025 & Phys. Rev. Lett. 2026

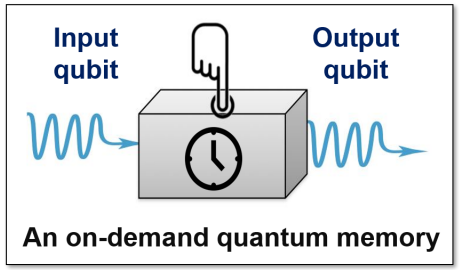
Privacy: No one should be able to guess another's vote
Verifiability: Every agent should be able to check that their vote is correctly recorded
Correctness: The final result of the election should be accurate

Developing advanced quantum networking capabilities

Generating, distributing, allocating, consuming the entanglement resource
at long distances – quantum internet
in clusters of interconnected quantum processing units – quantum data centers

Optical Quantum Interconnects:
a requirement for scaling up





Converting qubit frequency and encoding between heterogeneous platforms

Extracting photons from QPUs

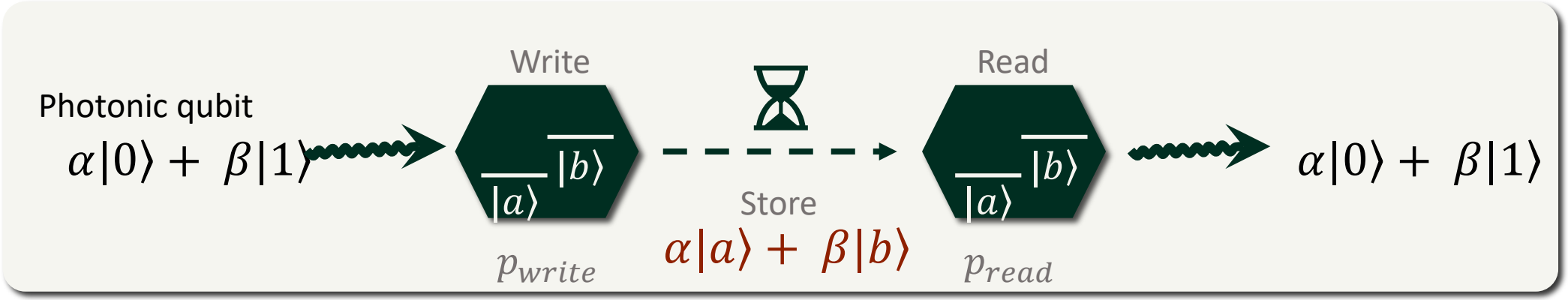
Storing quantum states for synchronization

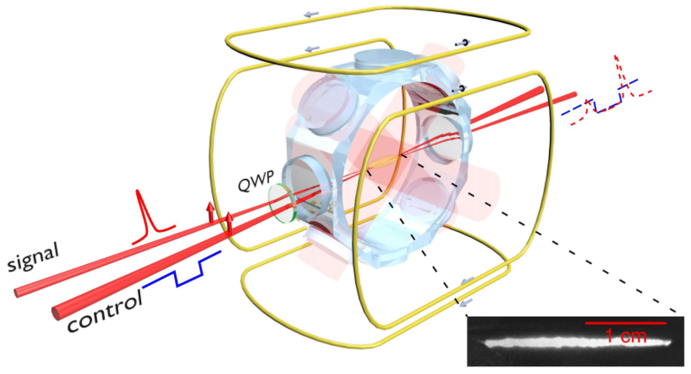
Transferring quantum states at long distances via repeaters

D. Awschalom *et al.*, *Development of quantum interconnects (QuICs) for next-generation information technologies*, PRX Quantum 2021

Highly-efficient optical quantum memory

Efficient, reversible, on-demand memory based on a large ensemble of cold atoms
Absorptive memory based on dynamic Electromagnetic Induced Transparency (EIT)





Crucial features: storage-and-retrieval efficiency, storage time, fidelity, signal-to-noise ratio, bandwidth, wavelength, multimode capability,…

Qubit fidelity > 99%
Lifetime around 20 µs
Storage and retrieval effiency 90%

Julien Laurat's group

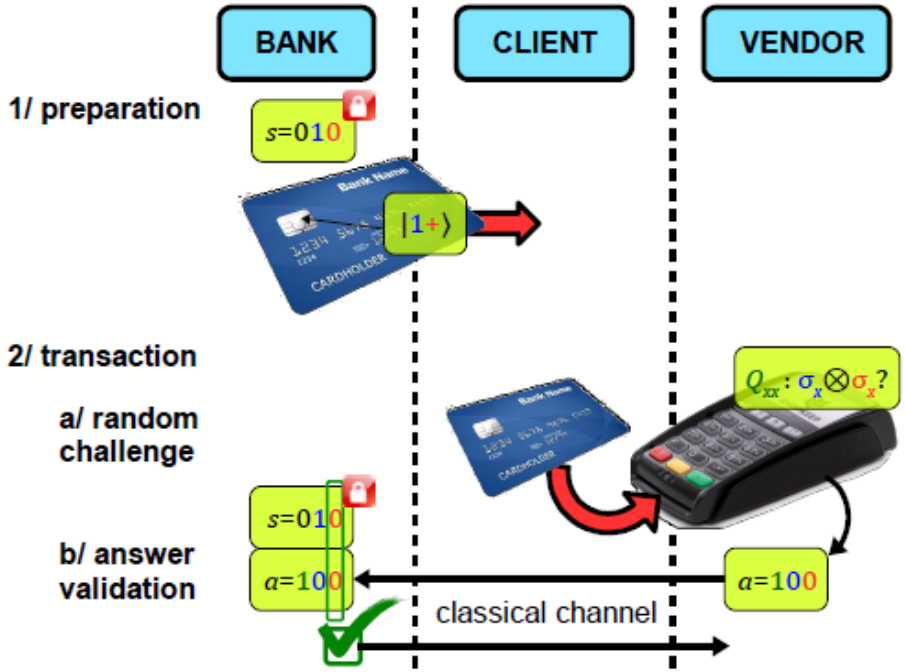
M. Cao, F. Hoffet *et al.*, Optica 2020

Unforgeable quantum money
Wiesner's original idea (1973) of using the uncertainty principle for security

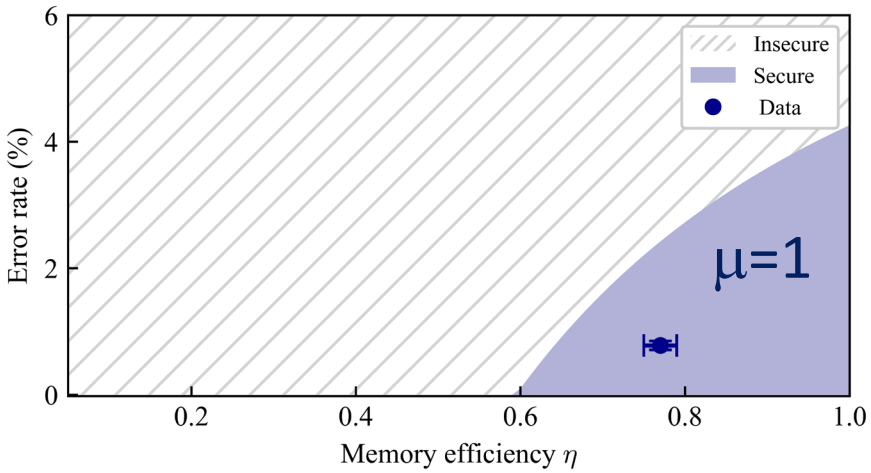
Previous implementations were on-the-fly

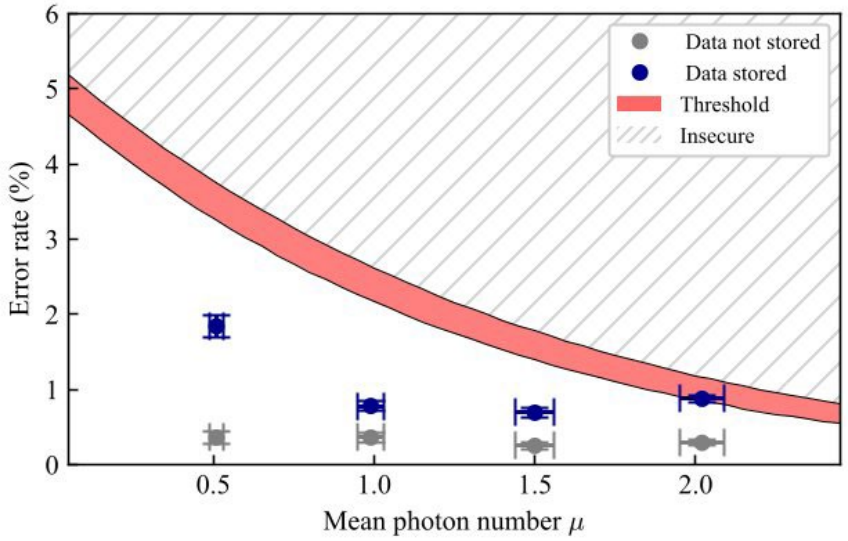
Challenge: incorporate an intermediate quantum memory layer while preserving security

Stringent requirements on the memory performance
→ high efficiency
→ very low noise

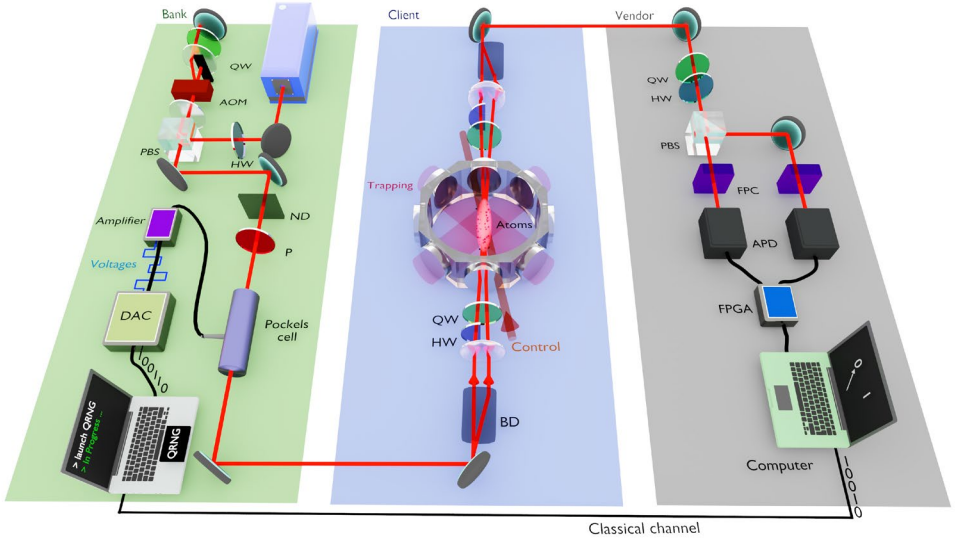


Experimental demonstration





Protocol secure if error rate falls below a specified threshold, highly dependent on the mean photon number per pulse and on the memory storage-and-retrieval efficiency

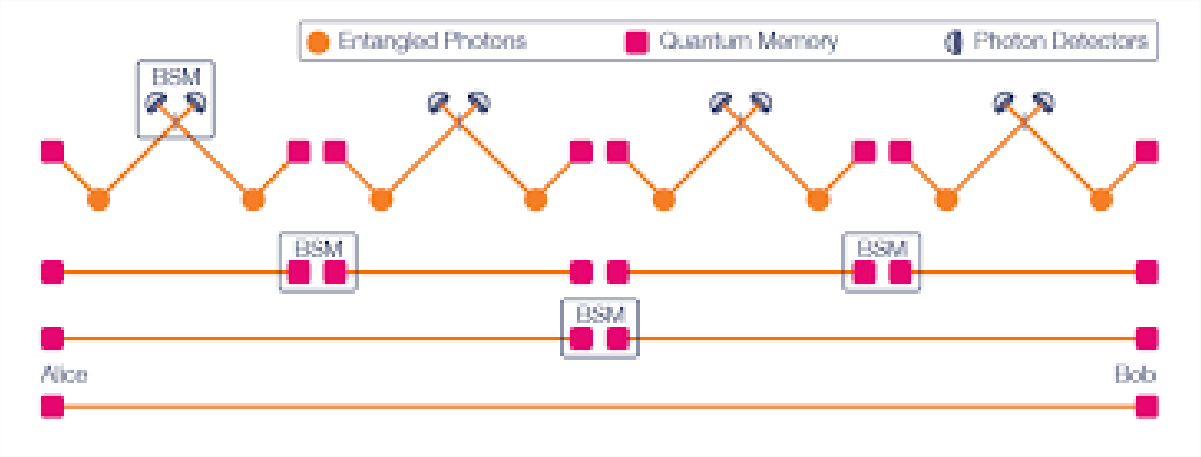


Highly-efficient quantum memories allow for implementations previously considered out of reach

H. Mamann T. Nieddu, F. Hoffet, M. Bozzio, F. Garreau de Loubresse, I. Kerenidis, ED, A. Urvoy, J. Laurat, Science Advances 2025

Quantum information networks

QUANTUM INTERNET ALLIANCE



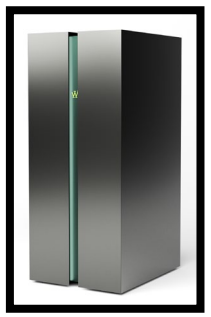
Create efficiently end-to-end entangled resources
Fundamental for interconnecting devices via teleportation over long distances

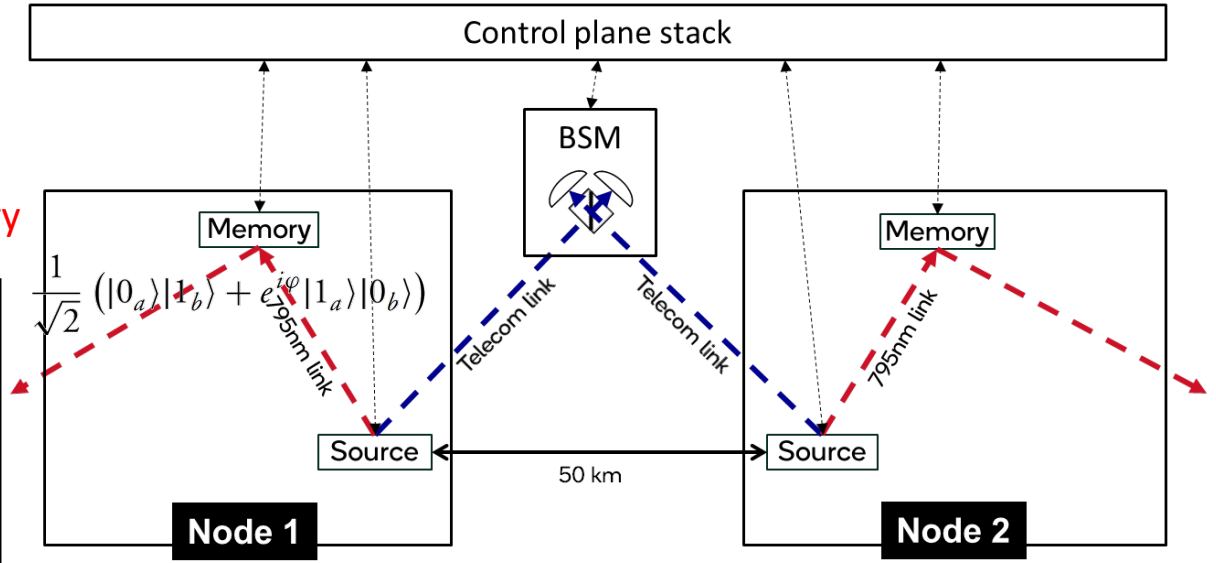
Trade-offs in critical benchmarks: memory efficiency and storage time, entanglement rate, range,…

Target performance:
Quantum repeater links with 50 bit/s over 50 km, >97% fidelity
In longer term, 500 km
Full network stack for use cases in server-client scenarios, e.g., blind quantum computing

Welinq

Industry-grade quantum memory





Non-degenerate (Rubidium-telecom), narrow-band photon-pair source

Deploying a quantum communication infrastructure in France

Benchmarking with commercial systems
Efficient PQC-secured trusted-node QKD exchange

Y. Piétri *et al.*, arXiv: 2504.01454

Deployment of CV-QKD industrial prototype

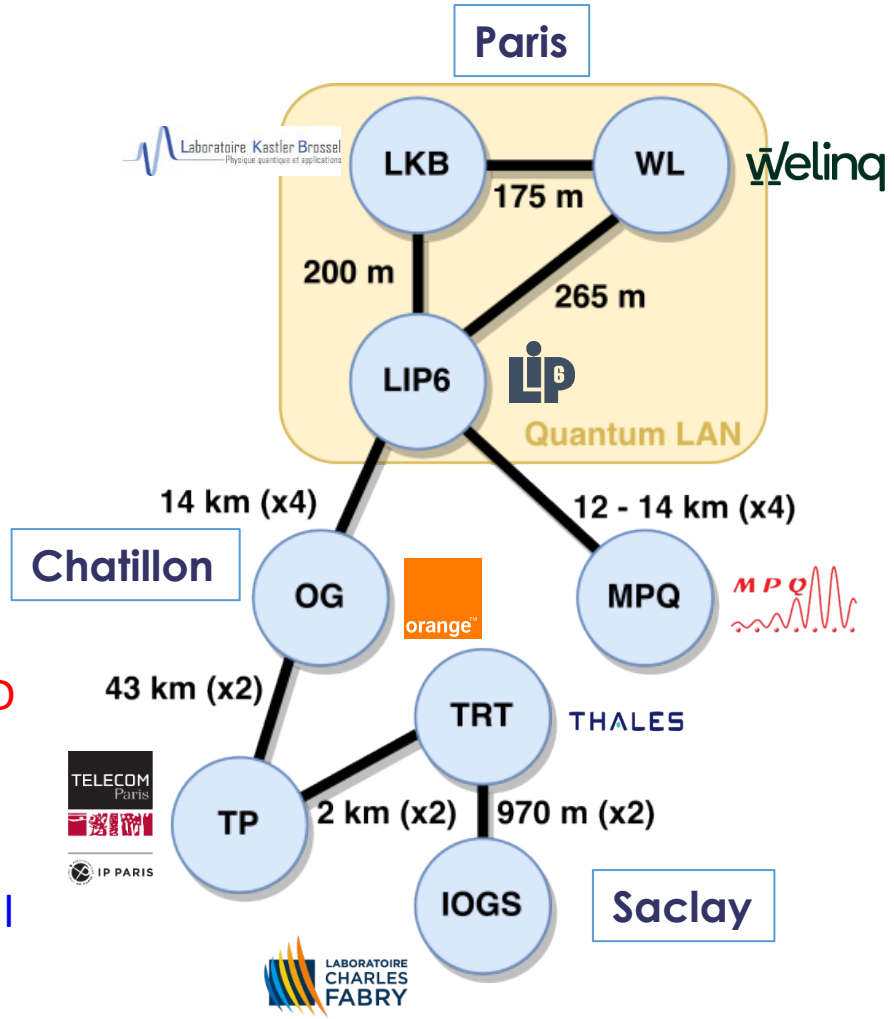
exail

Long term secure storage with QKD

VeriQloud

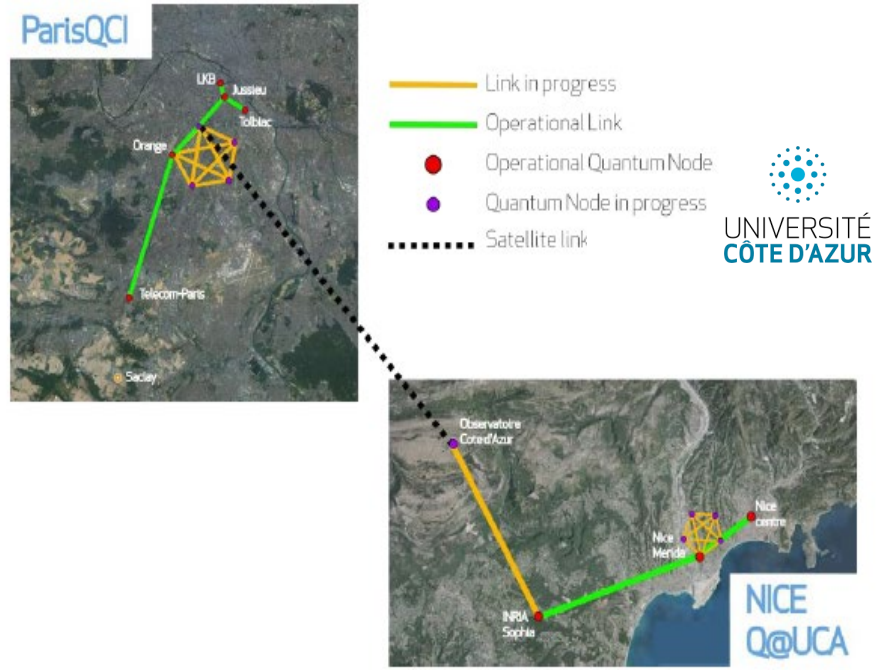
Deployment of links with industrial quantum memories

Welinq

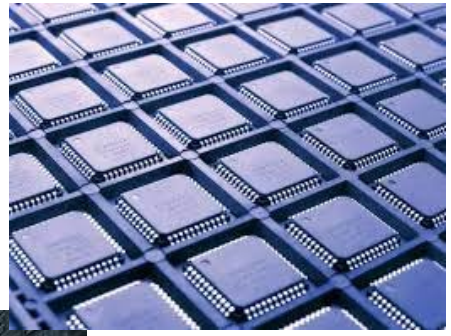


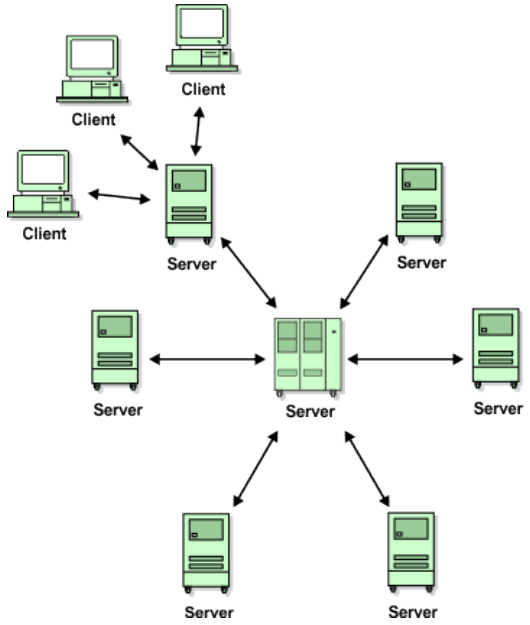
Integration of time and frequency distribution infrastructure

Interface with Nice testbed including Optical Ground Station of the Côte d'Azur Observatory



An era of quantum connectivity





Conception and implementation of high-performance interconnection systems in modular, heterogeneous, resilient architectures

ED and J. Laurat., *Quantum connectivity for scale*, Optics and Photonics News, February 2026

Thank you!

Yoann Piétri, Matteo Schiavon, Valentina Marulanda Acosta, Amine Rhouni, Alexis Rosio, Manon Huguenot, Baptiste Gouraud, Philippe Grangier

Thomas Liège, Caroline Lim, Jean-Marc Conan, Perrine Lognoné, Daniele Dequal

Nicolas Laurent-Puig, Laura dos Santos Martins, Simon Neves, Verena Yacoub, Mathieu Bozzio, Hadriel Mamann, Julien Laurat, Iordanis Kerenidis,
Ivan Šupić, Damian Markham