QuReP

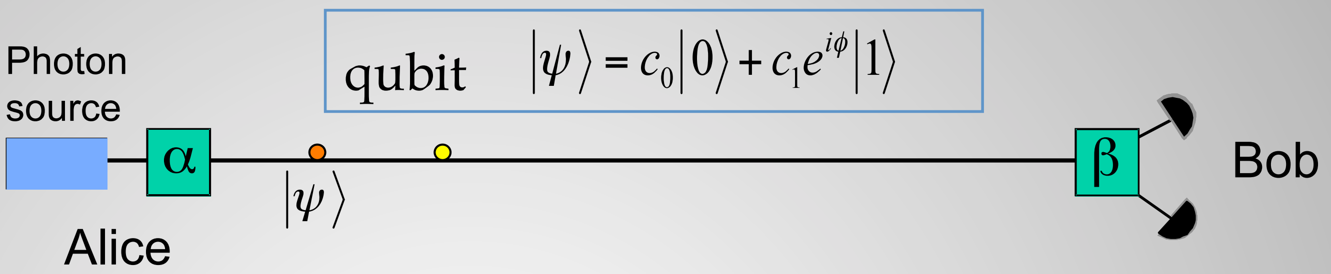
Quantum Repeaters for Long Distance Fibre-Based Quantum Communication

Rob Thew

Coordinator: Nicolas Gisin

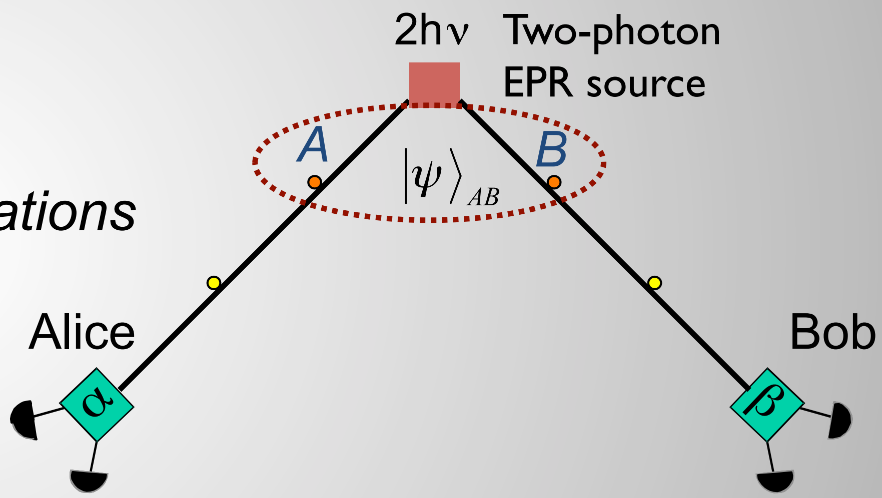
Quantum Communication

1. Direct transmission



2. Entanglement distribution:

Goal is to distribute quantum correlations between Alice and Bob using entangled qubits.



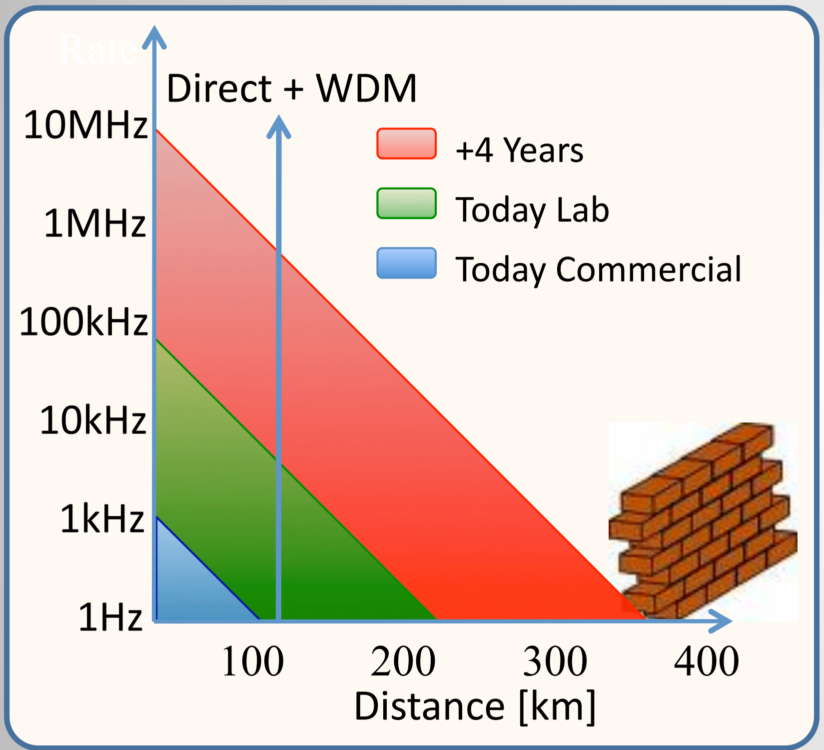
Entanglement can be used for:

- *Quantum Cryptography*
- *Transmit arbitrary quantum state via quantum teleportation*

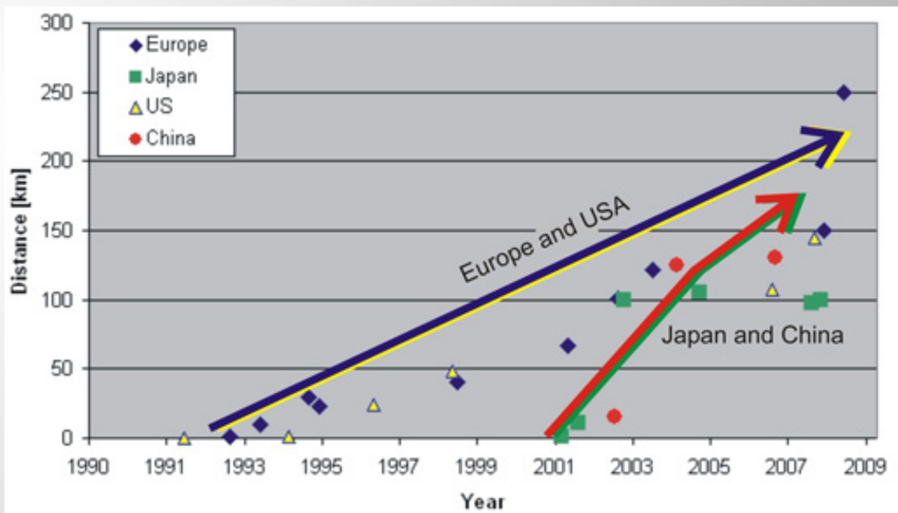
Universal resource for Q communication
Can be transmitted efficiently with Quantum repeater architecture

Quantum Communication

Distribution of secret randomness for cryptographic purposes governed by the laws of quantum physics.



Comparison of the maximum range achieved by research groups for different geographic regions over time.

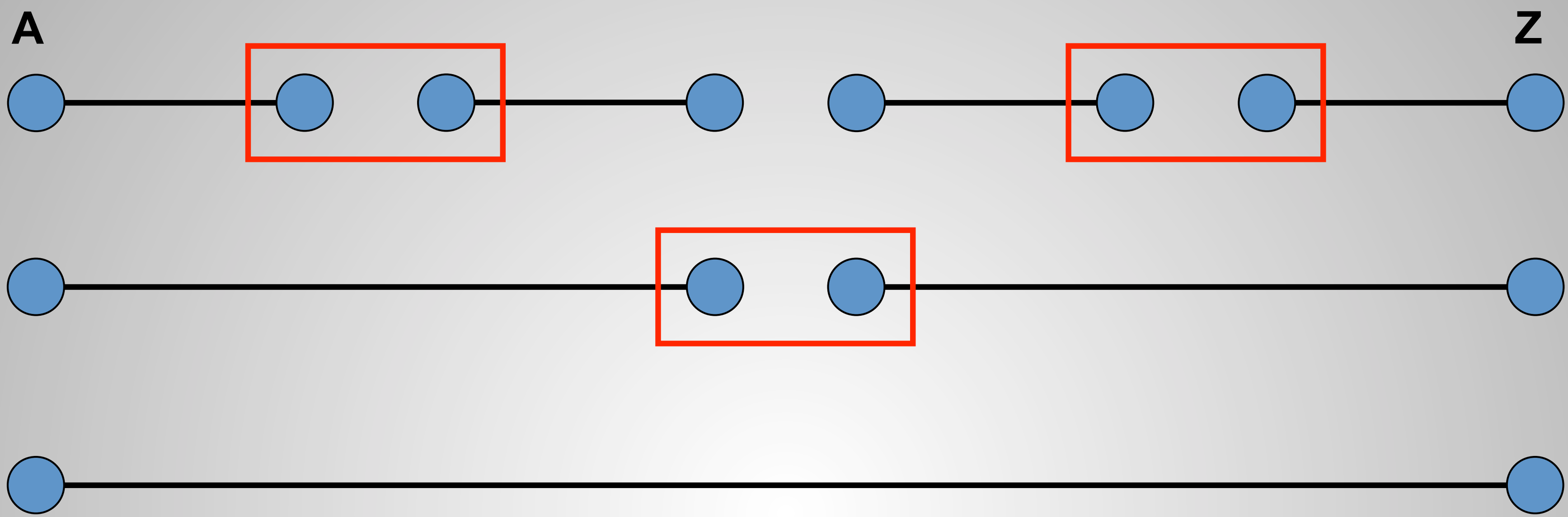


Limit

- 1000km of fibre at optimal wavelength – transmission **10^{-20}**.
- **3000 years** to distribute 1entangled pair with 1 GHz source.
- Straightforward amplification impossible **(no cloning!)**.

Potential Solution: quantum repeaters

Quantum Repeater - Principle



Create entanglement **independently** for each link. Extend by swapping.

n links with transmission *t* each

Direct transmission:- $T \sim \frac{1}{t^n}$

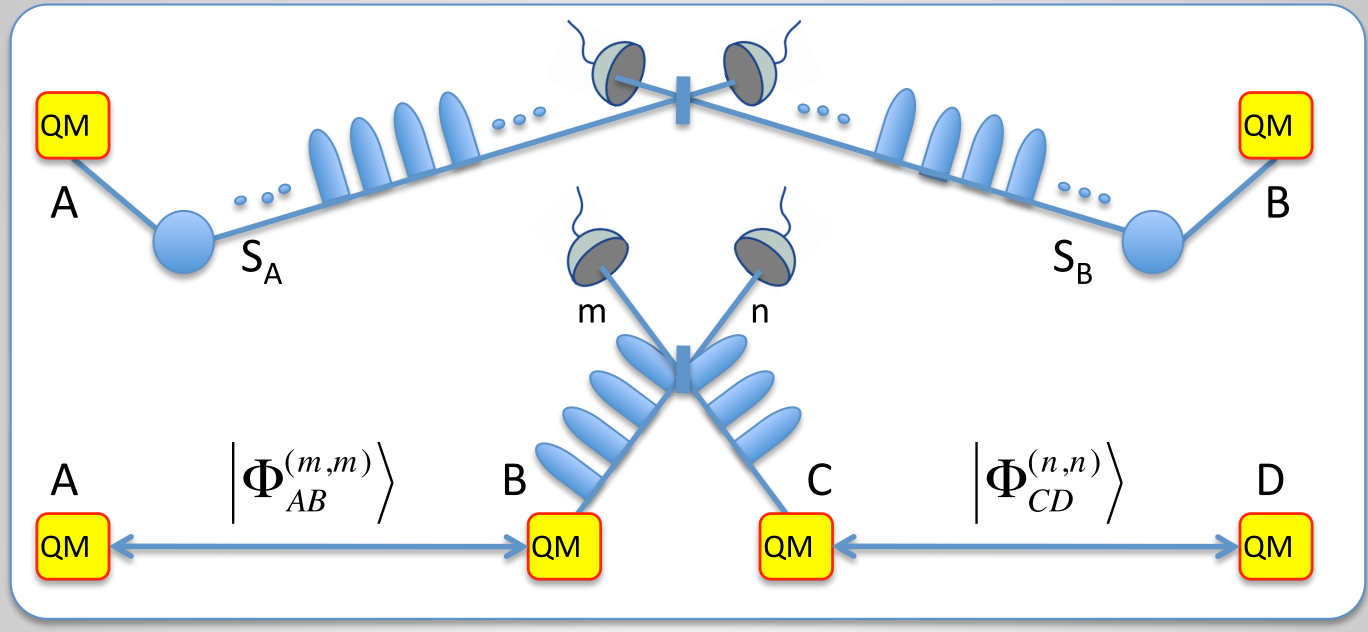
Repeater:- $T \sim \frac{1}{t}$

Requires

1. Distribution of Entanglement
   - Basic resource
2. Entanglement Swapping
   - Joint measurement
3. Quantum Memories
   - Coherent storage

http://quantumrepeaters.eu

Quantum Repeaters for Long Distance Fibre-Based Quantum Communication



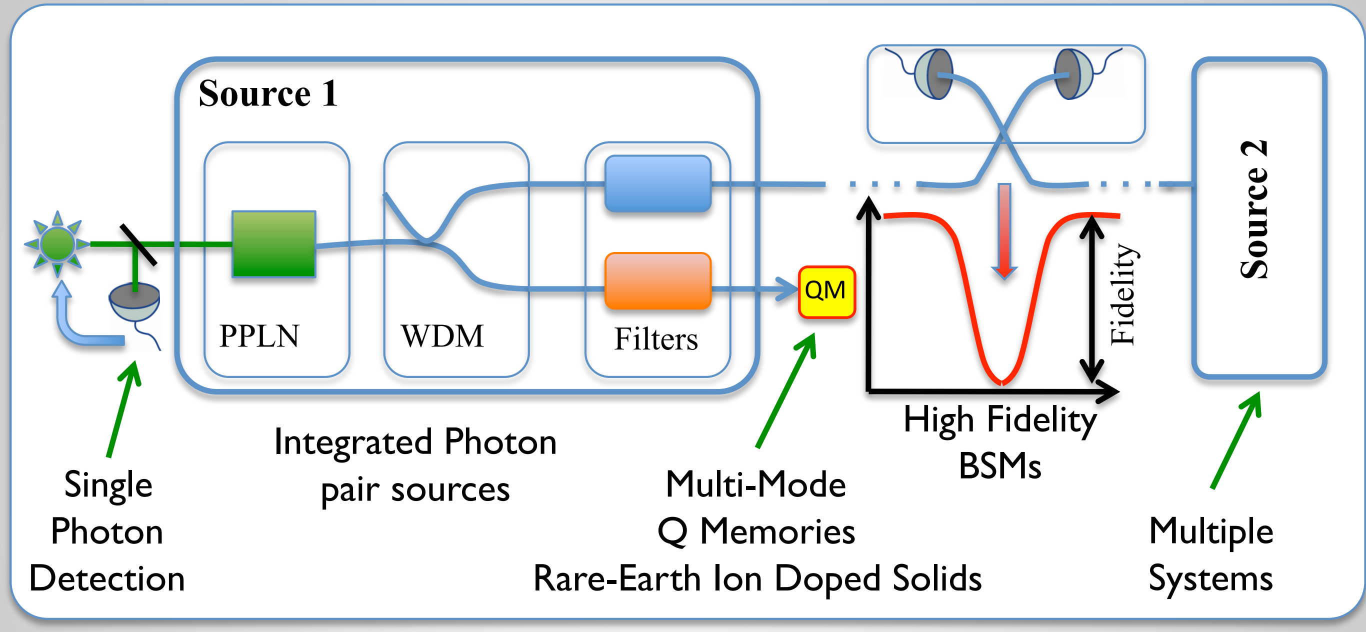
The goal of QuReP is to develop a Quantum Repeater - the elementary building block required to overcome current distance limitations for long-distance quantum communication.

→ **The analogue of the classical repeater (amplifier)**

QuReP

http://quantumrepeaters.eu

Quantum Repeaters for Long Distance Fibre-Based Quantum Communication



Switzerland: - Université de Genève
- ID Quantique SA

Sweden: - Lunds Universitet

Germany: - Universität Paderborn, DE

France: - Laboratoire Aimé Cotton
- Laboratoire de Chimie de la Matière Condensée de Paris
- Université Pierre et Marie Curie

QuReP

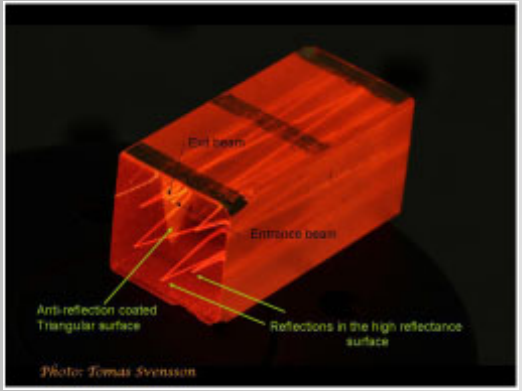
http://quantumrepeaters.eu

LUND UNIVERSITY

Quantum Information Group

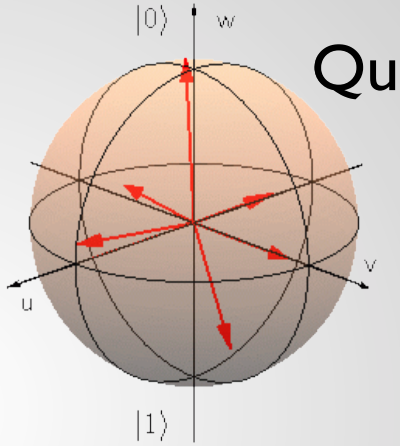
Specialising in rare earth crystals

http://www-atom.fysik.lth.se/QI/ stefan.kroll@fysik.lth.se



Quantum Memories

Efficiency 35%
Spin storage > 100μs

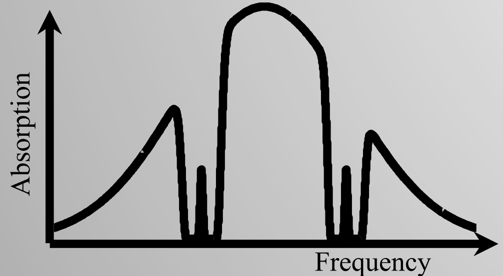


Quantum Computing

Demonstrating qubit-qubit-like control as a mechanism for two-qubit gate operations

Arbitrary qubit operations, Fidelity > 90% as determined by quantum state tomography

Spectral Tailoring for Creating:



Narrow-band Spectral filters

Polarisation dependent slow light filters with large delay time–bandwidth product

Slow Light Structures

30 dB spectral filtering with MHz resolution, combined with 1000 m/s slow light structures for simultaneous spectral & temporal signal filtering

Laser Stabilisation

Laser frequency stabilisation to crystals instead of cavities.

Development of theory as well as experimental implementation

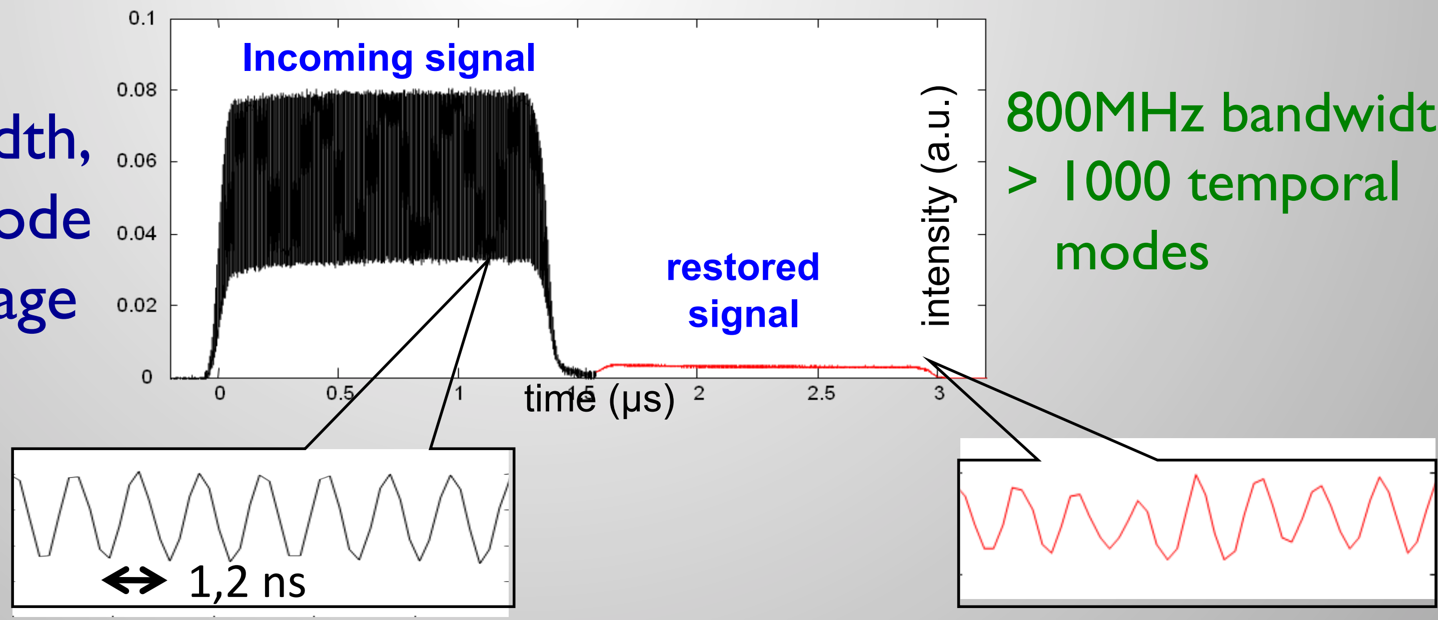
Laboratoire Aimé Cotton

- Expertise
  - Atomic spectroscopy
  - Light/matter interaction near resonance
  - Optical coherent transients
  - Frequency-agile semiconductor lasers
  - Rare-earth ion doped crystals

- Current research projects
  - Analog broadband processing of optically carried RF signals
  - Quantum memories in Tm^{3+} doped crystals

Tm^{3+}: YAG

Large bandwidth, highly multimode capacity storage



800MHz bandwidth

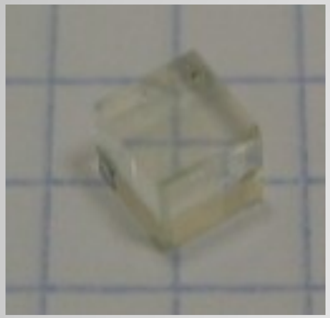
> 1000 temporal modes

T. Chanelière, A. Chauvet-Louchet, J.-L. le Gouët

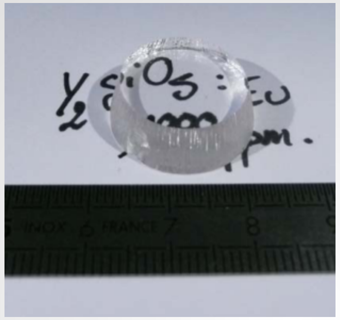
http://www.lac.u-psud.fr

Ecole Nationale Supérieure de Chimie de Paris

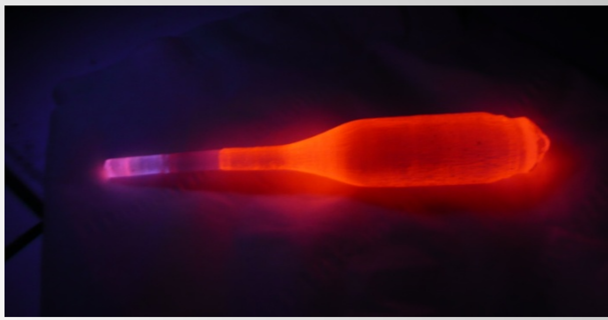
- Material development, **crystal growth**



Pr:$La_2(WO_4)_3$



Eu:Y_2SiO_5



Eu:Y_2SiO_5 under UV excitation

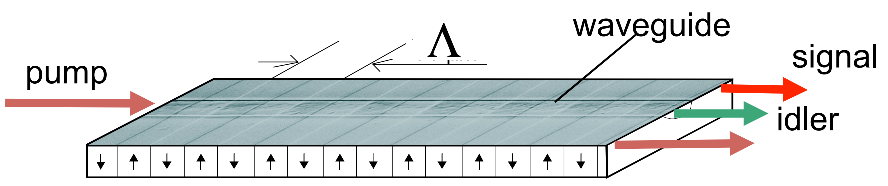
- Optical spectroscopy conventional & **coherent: Pr^{3+}, Eu^{3+}, Nd^{3+}**

  Optical and Raman coherent lifetimes, hole-burning
- EPR spectroscopy
- Level structure prediction, magnetic field effects

University of Paderborn
Group of Applied Physics / Integrated Optics

Goal: Development of quantum memory compatible, narrowband, SPDC-based two-color photon pair sources

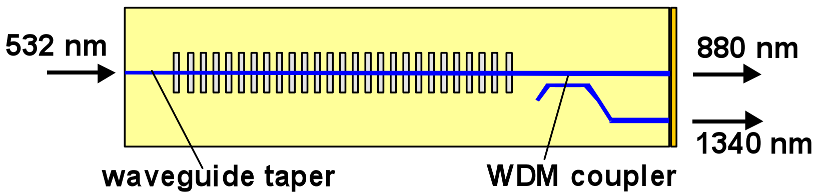
Approach: Integrated optical devices and circuits in periodically poled **$LiNbO_3$** (PPLN) of increasing complexity



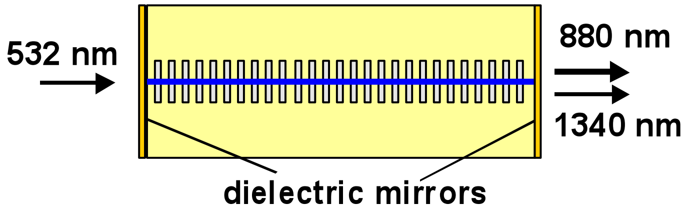
- **Efficient photon pair generation using SPDC in waveguides**
- **Ti-indiffusion and proton exchange as waveguides fabrication techniques**
- **Exploiting type I and type II phase-matching**
- **Challenges:**
  - **Narrowband emission**
  - **Short period domain gratings**
  - **Integration with other components**

Future tasks:
Devices of increased functionality

Source with integrated WDM coupler



Resonantly enhanced SPDC source



UNIVERSITÄT PADERBORN

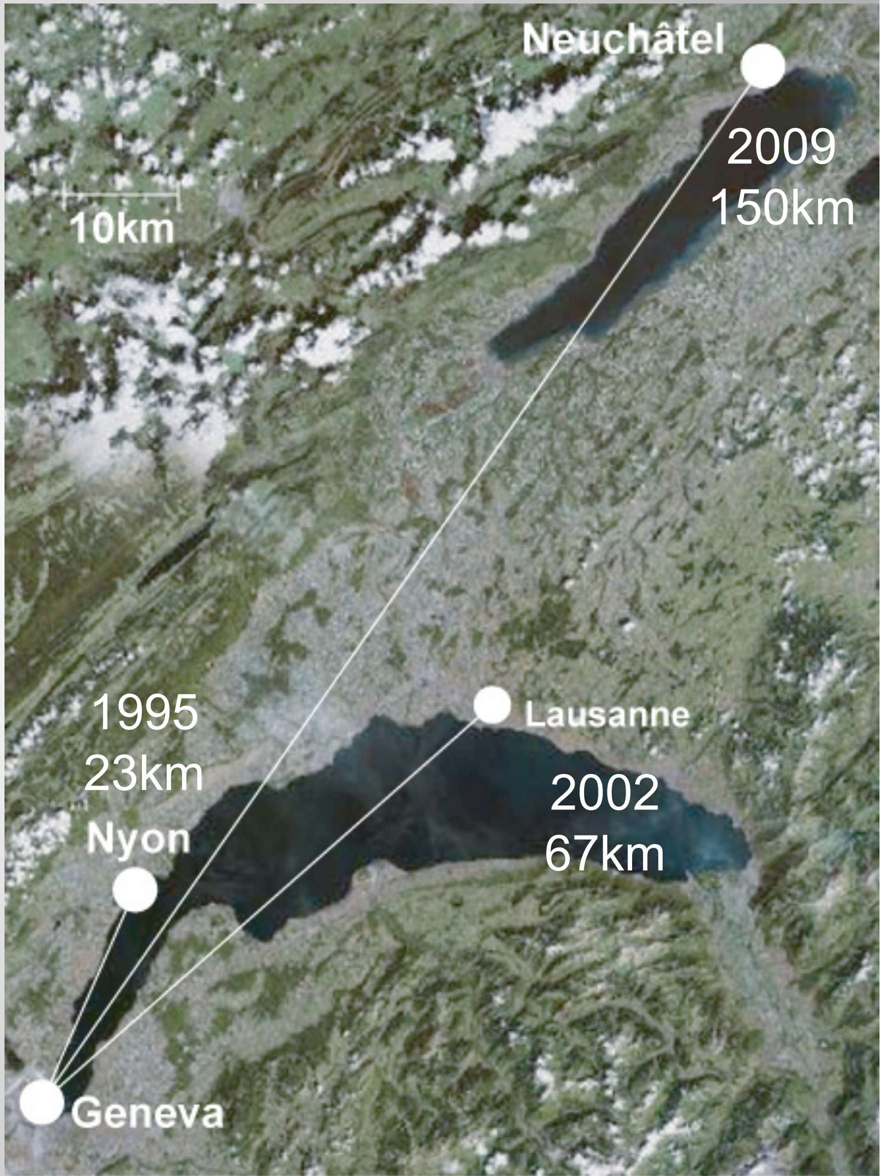
Wolfgang Sohler / Christine Silberhorn
http://fb6www.uni-paderborn.de/ag/ag-sol

Nicolas Gisin, Hugo Zbinden, Mikael Afzelius

University of Geneva: Group of Applied Physics

Taking Quantum Communication from concept to the real world

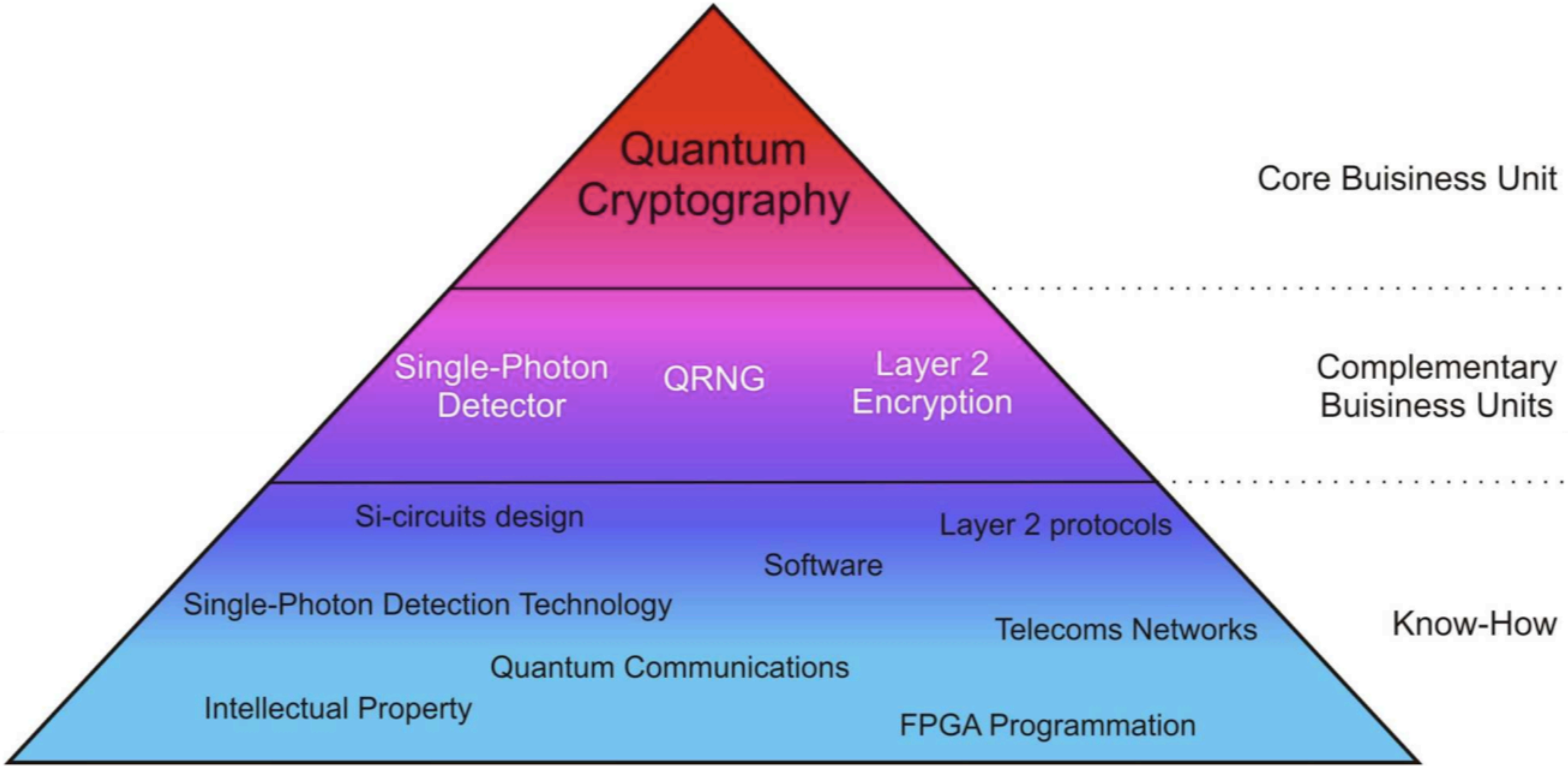
- Quantum Memories (QM)
  - Theory/experiment
  - Protocols and applications
- Photon Pair Sources
  - Adapted for telecommunication & QMs
- Detectors
  - InGaAs & Silicon SPADs
  - Superconducting
- Q Communication (QKD)
  - Theory & Experiment
- Foundations
  - Nonlocality / Entanglement



Virtual Institute of Quantum Communication
http://qurope.eu/vi/q-comm

http://www.gapoptic.unige.ch

id Quantique competencies

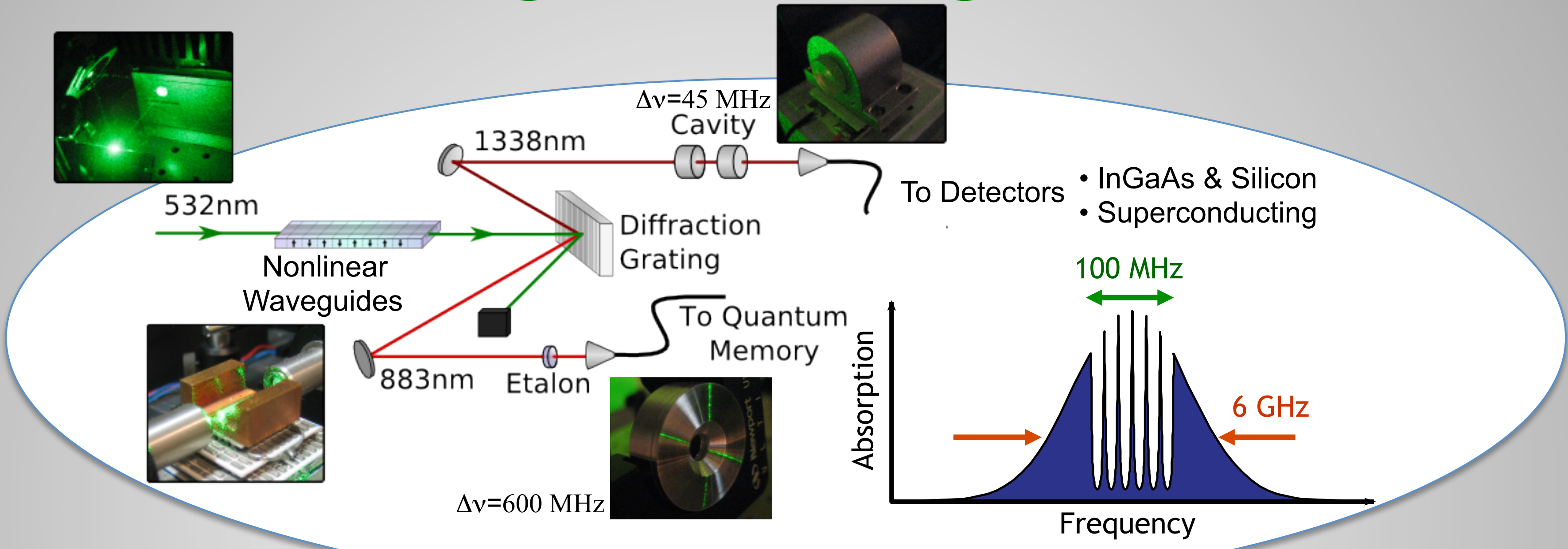


www.idquantique.com
matthieu.legre@idquantique.com

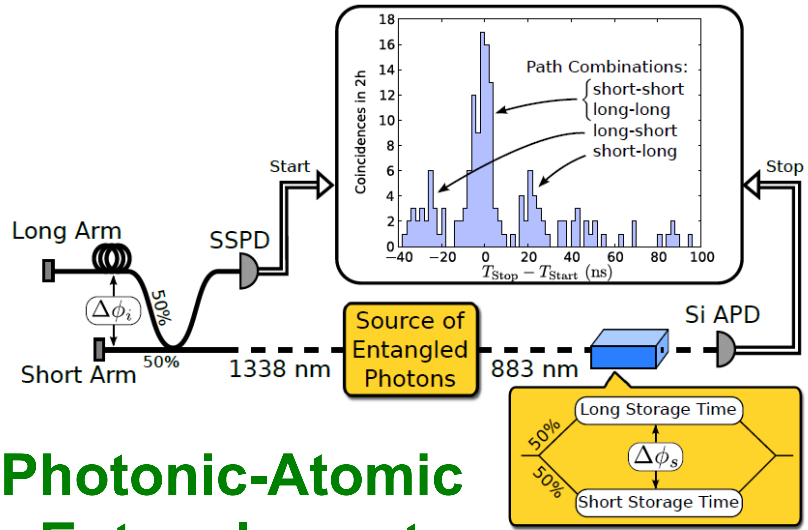
IDQ FROM VISION TO TECHNOLOGY

http://quantumrepeaters.eu

Putting it ALL Together

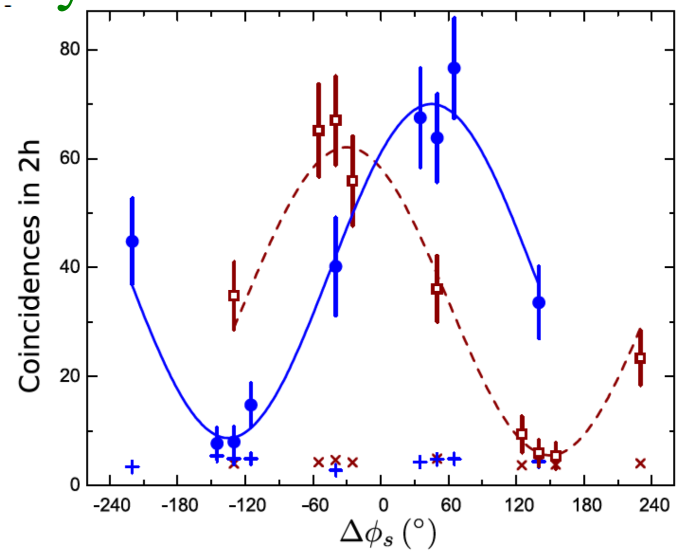


Violation of Bell-CHSH inequality



Photonic-Atomic Entanglement

$S = 2.64 \pm 0.23$



C. Clausen *et al.*, Sub. Nature

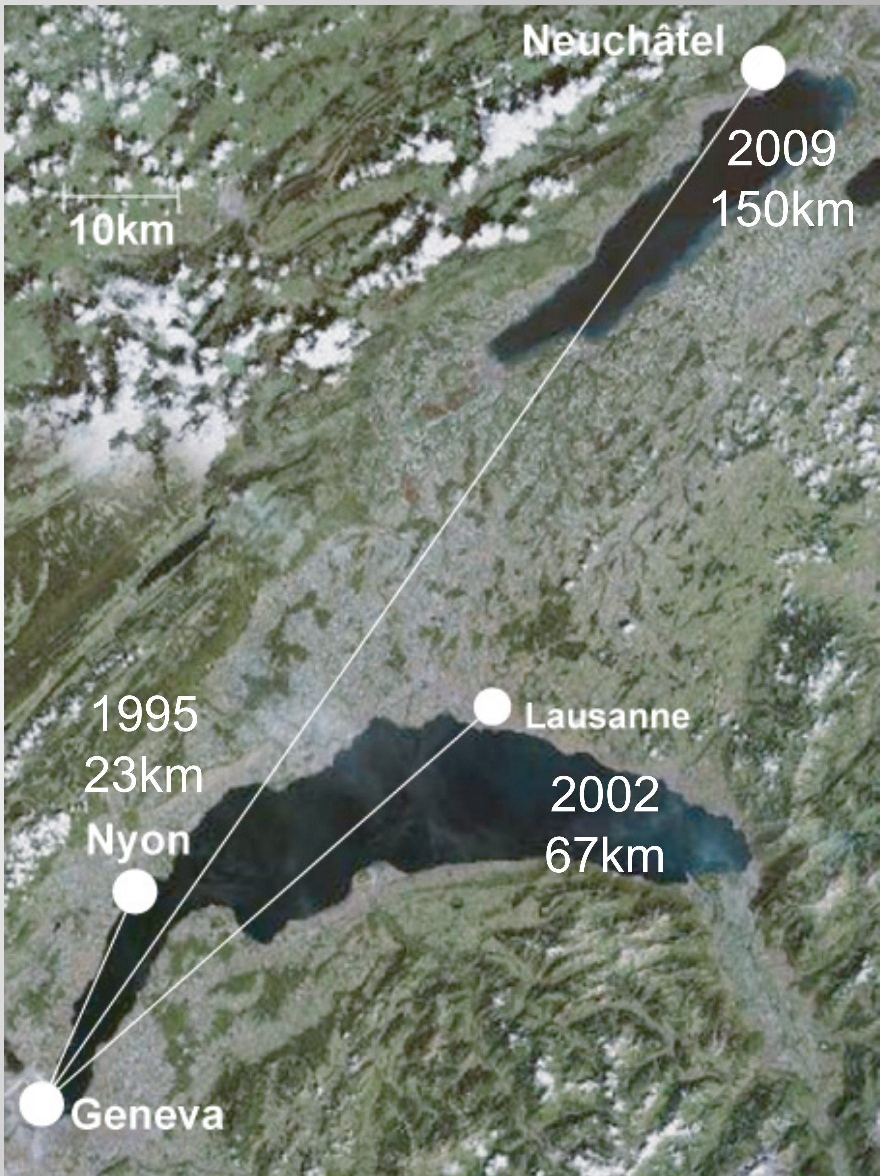
QuReP: Quantum Repeaters for Long Distance Fibre-Based Quantum Communication

○ Readying the technology for an industrial project over the next 5-10 years

○ Major technical challenges & solutions are being identified

○ Early results have been promising and their industrial exploitation perspective are being analysed

○ A synergetic partnership of collaborators from diverse fields has been brought together to realise this project.



Developing the elementary building blocks required to overcome current distance limitations for long-distance quantum communication

QuReP

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