UNIVERSITÉ DE GENÈVE

Integrated Photonics, Entanglement & Quantum Networks

Rob Thew

Quantum Technologies

Department of Applied Physics

FNSNF

QSIT Quantum Science and Technology

National Centre of Competence in Research

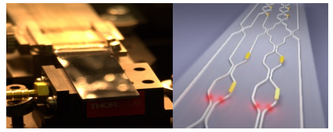
cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

QUANTUM FLAGSHIP

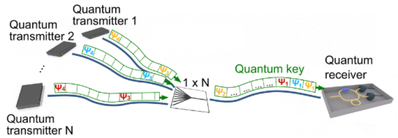
EURAMET

UNIVERSITÉ DE GENÈVE

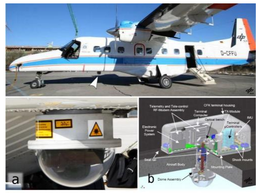
Quantum Communication



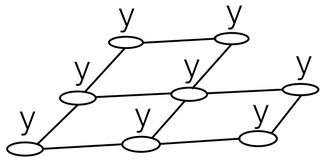
Smaller, Faster, Cheaper devices for QKD, QRNG



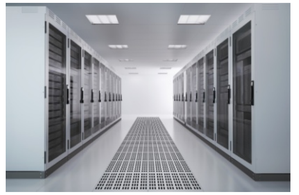
Network Architectures
(Backbone, access, Switching ..)



Air-based Quantum Communication



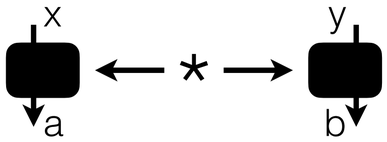
Sensor Networks



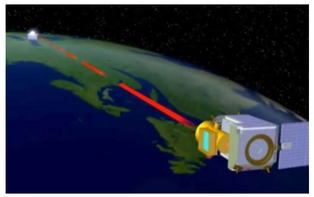
Cloud-based Quantum Computing

Implementation Security

New Quantum Primitives
Digital Signature, bit commitment …



Practical Prototypes for Device Independent Implementations

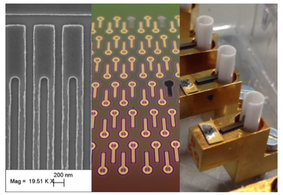


Quantum Communication with Satellites

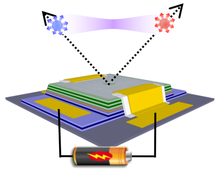
ETSI

Industrial Standards

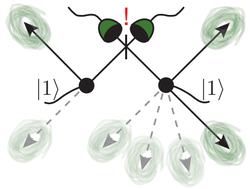
System & Device Certification



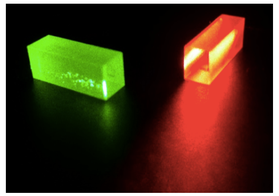
Photon Detectors



Quantum Sources



Quantum Relays & Networks



Quantum Memories

Global Communication with Quantum Repeaters

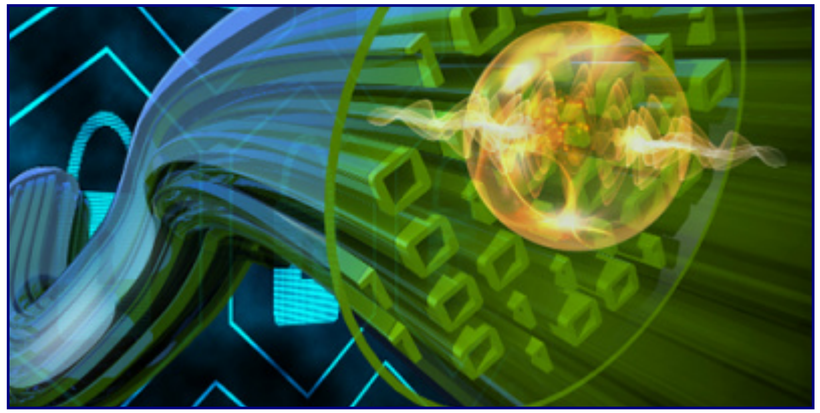
Fundamental to Applied - Research to Development

UNIVERSITÉ DE GENÈVE

Department of Applied Physics

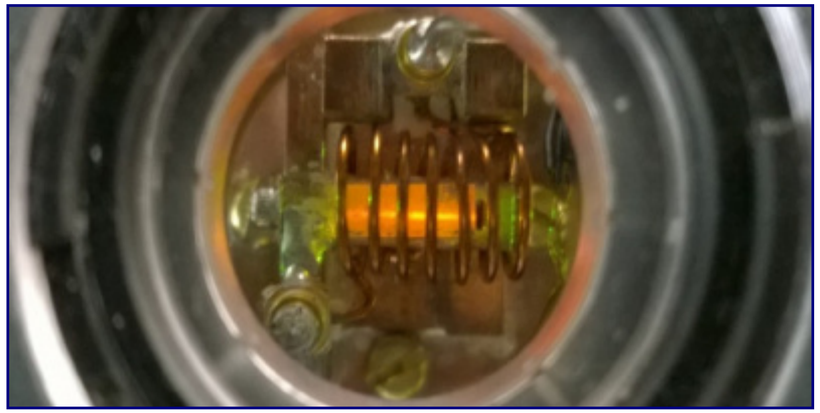
Quantum Information & Communication

Quantum Technologies
Zbinden + Thew



Quantum Cryptography
Quantum Networks
Quantum Photonics
Photon Detection
Quantum Biophysics
Quantum Metrology

Quantum Repeaters & Memories
Afzelius



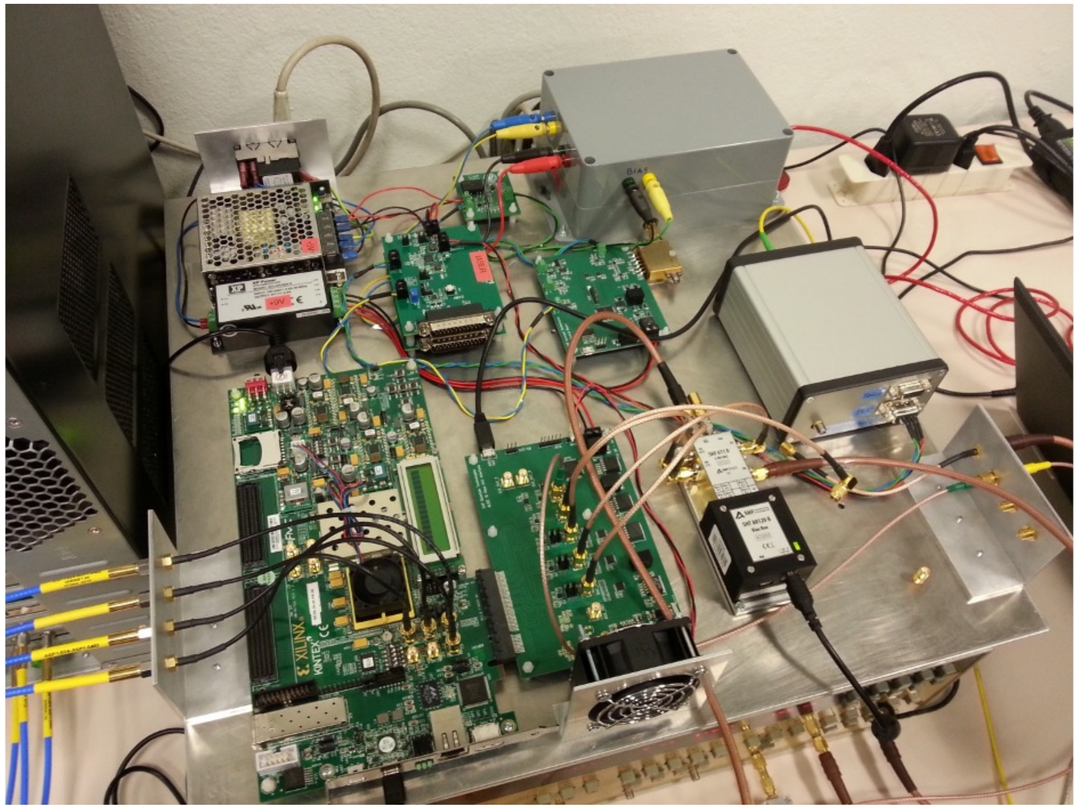
Quantum Memories
Quantum Photonics
Optical & Spin
Spectroscopy

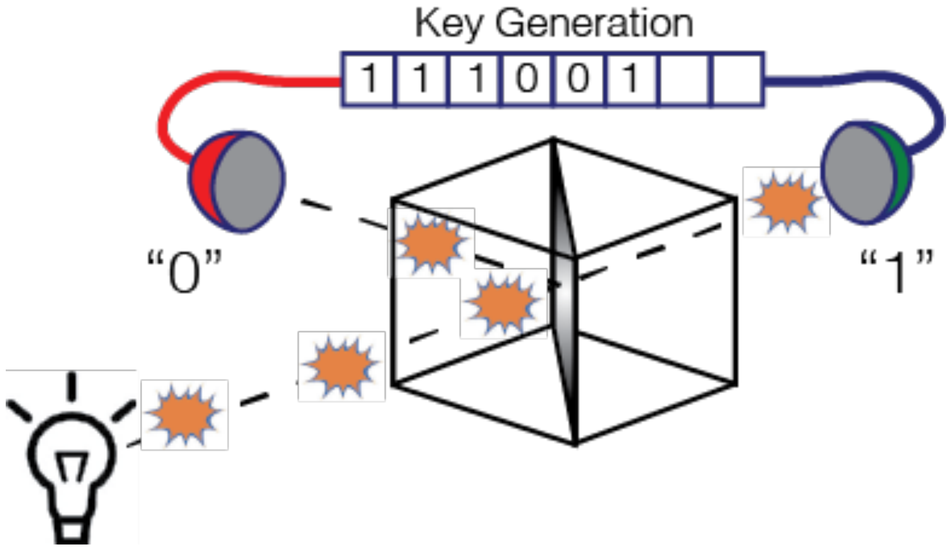
Quantum Theory
Brunner + Haack

Quantum Nonlocality
Quantum Thermodynamics
Device Independent
Quantum Information Processing

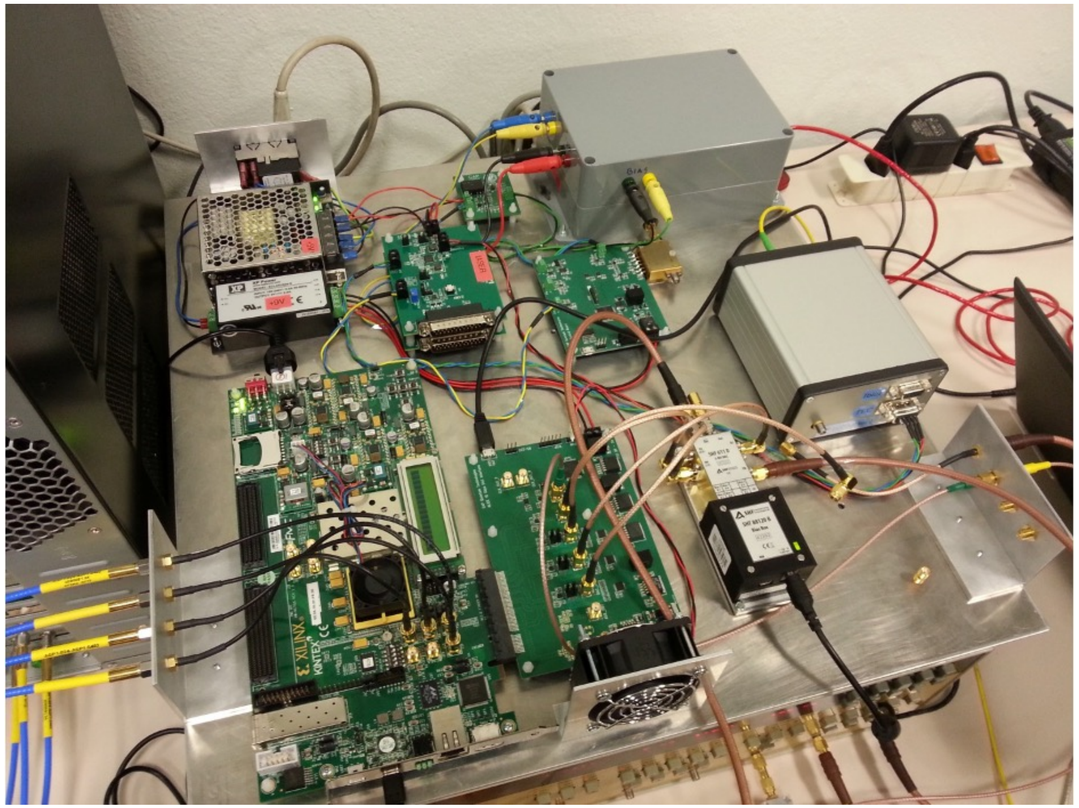
www.unige.ch/gap/qic/

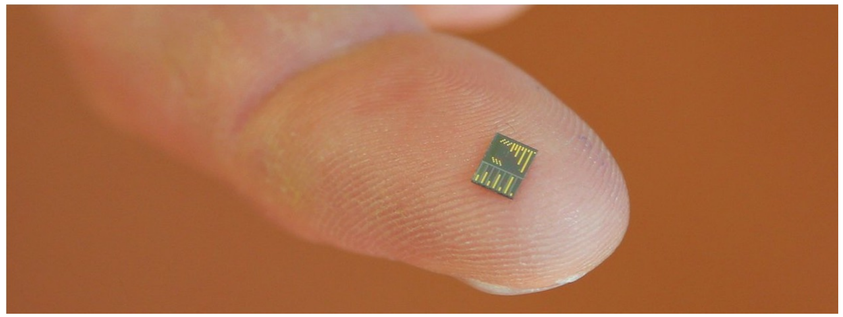
QRNG - Quantum Random Number Generation



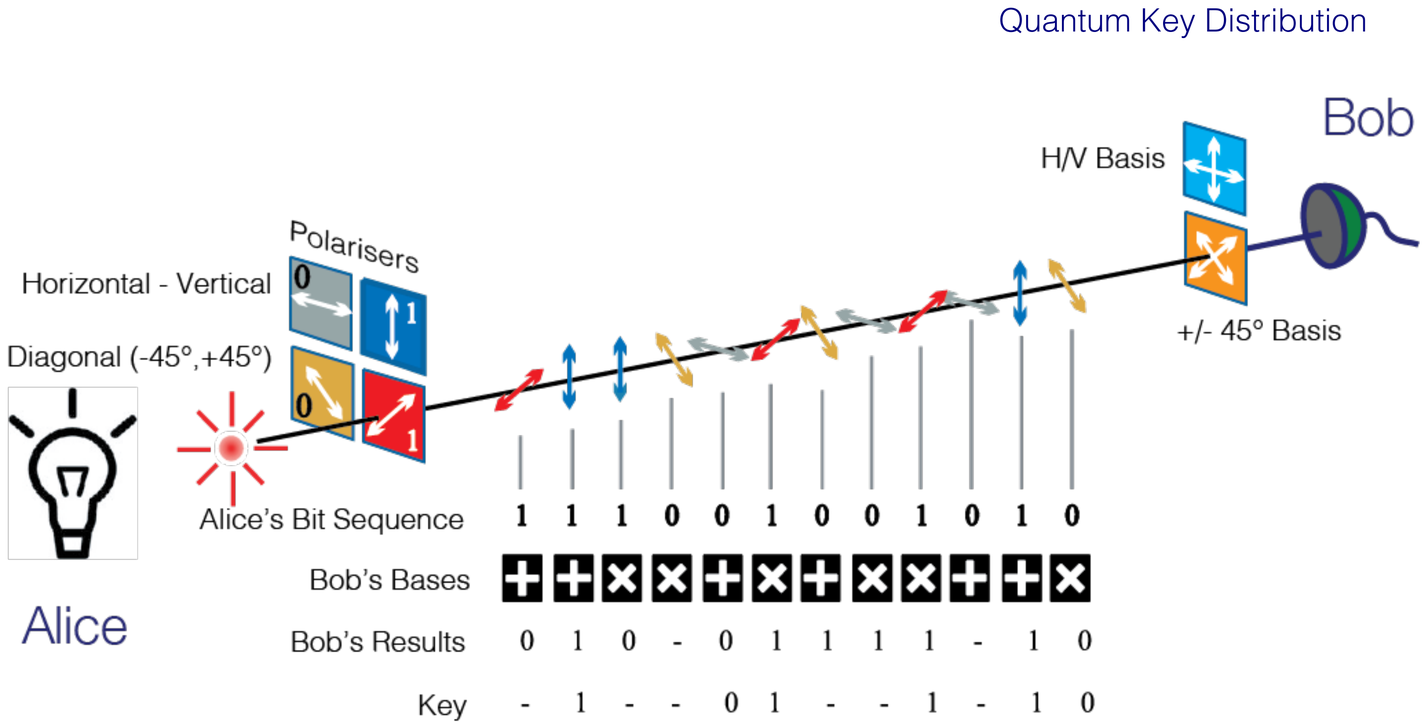


QRNG - Quantum Random Number Generation

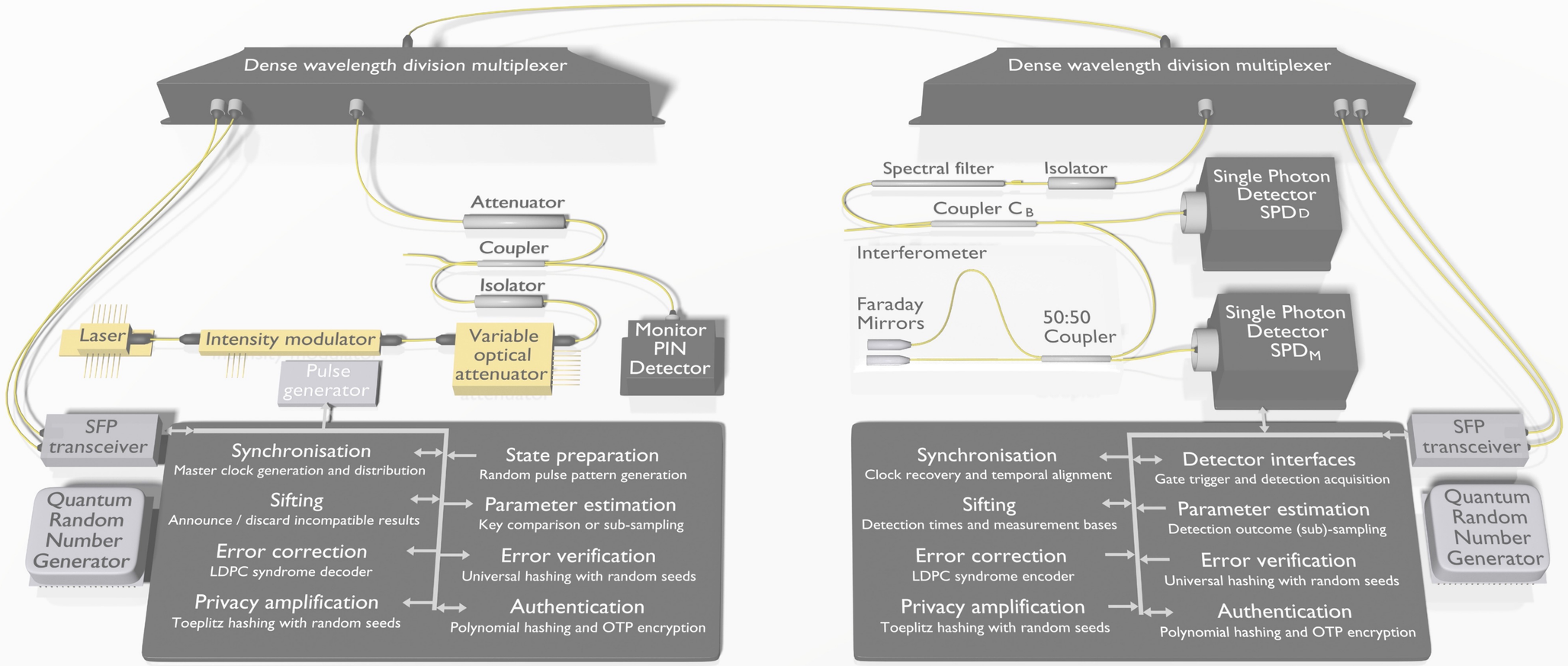




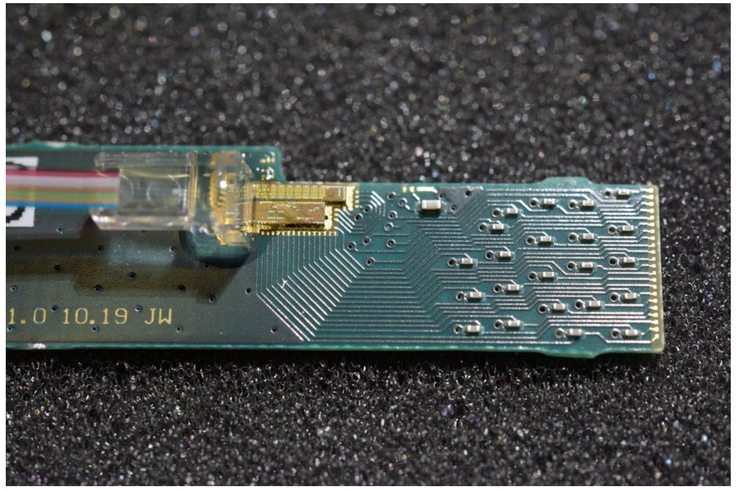
QKD - Quantum Key Distribution



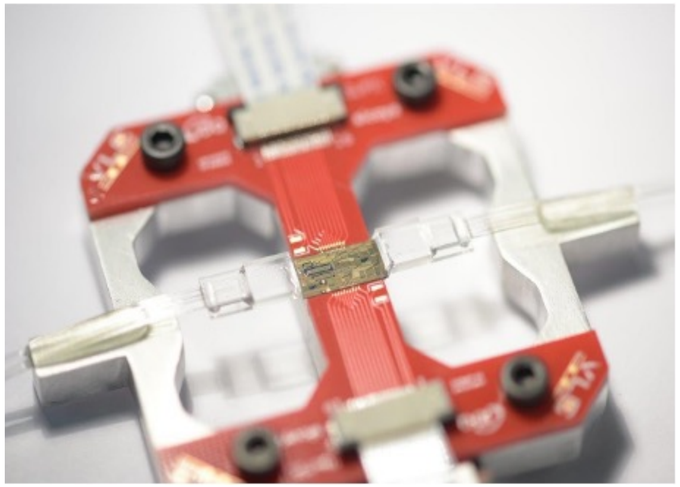
QKD - Quantum Key Distribution



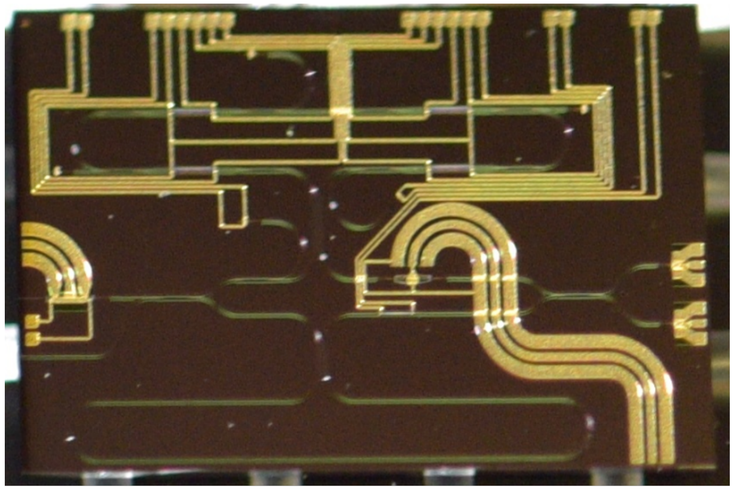
QKD - Quantum Key Distribution



Silicon Photonics (Alice)



Silicon Nitride, Silica on Silicon

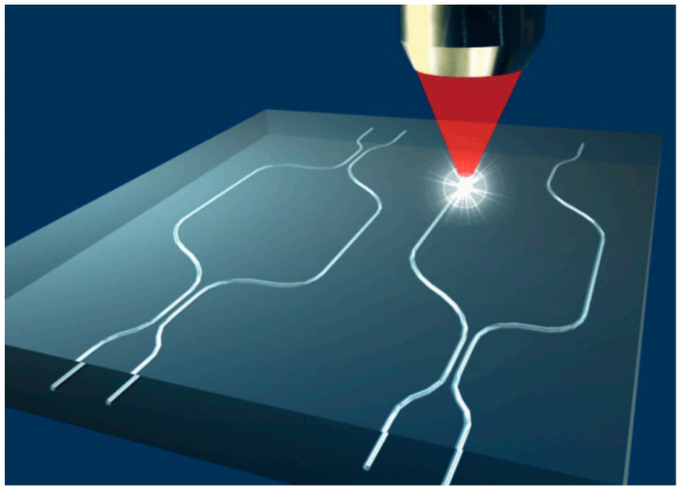


Everything Integrated

Laser source

Fast phase modulator

Balanced detectors

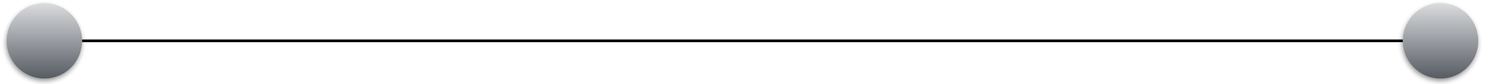


fs Laser written waveguides

Interferometers Complex circuits

R. Osellame, Milano Italy

Quantum Repeaters



A

B

Quantum Repeaters

Direct transmission: 1000km ($t = 10^{-20}$), 10GHz clock rate…1 photon/300 years!

A B

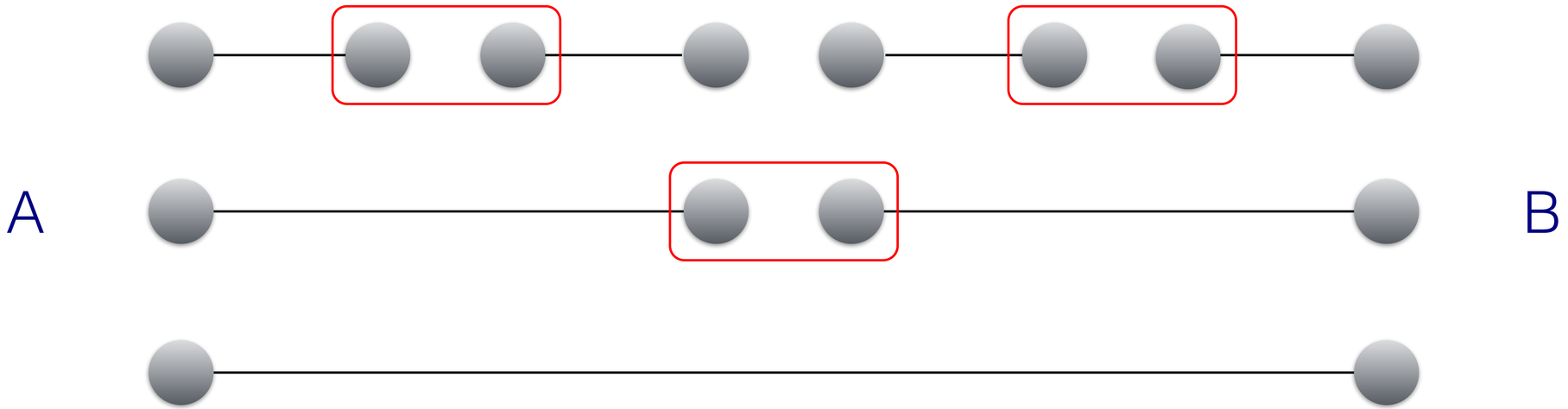
Consider n links with transmission t

Create entanglement independently for each link

N. Sangouard *et al.*, RMP **83**, 33 (2011)

Quantum Repeaters

Direct transmission: 1000km ($t = 10^{-20}$), 10GHz clock rate…1 photon/300 years!



Consider n links with transmission t

Create entanglement independently for each link

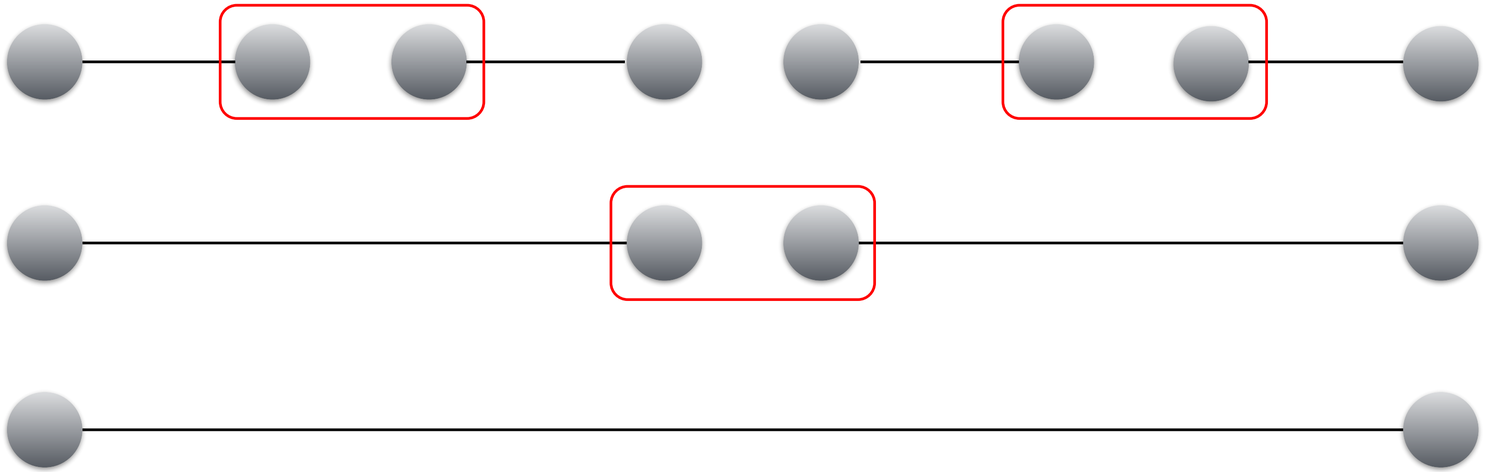
Extend by swapping (BSM)

N. Sangouard *et al.*, RMP **83**, 33 (2011)

Quantum Repeaters

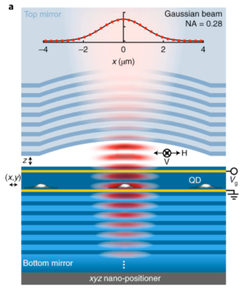
Direct transmission: 1000km ($t = 10^{-20}$), 10GHz clock rate…1 photon/300 years!

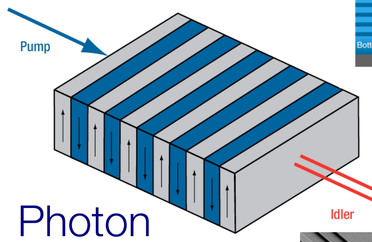
A



B

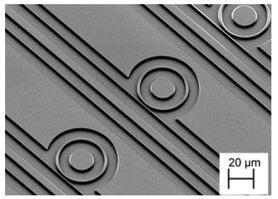
Single photon sources



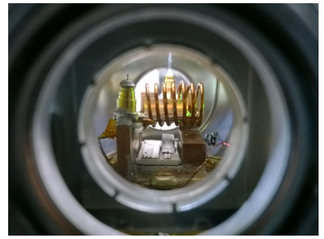


Photon pair sources

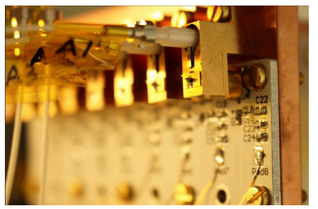
Quantum Frequency Conversion



Quantum Memories



Single Photon Detectors



Consider *n* links with transmission *t*

Create entanglement independently for each link

Extend by swapping (BSM)

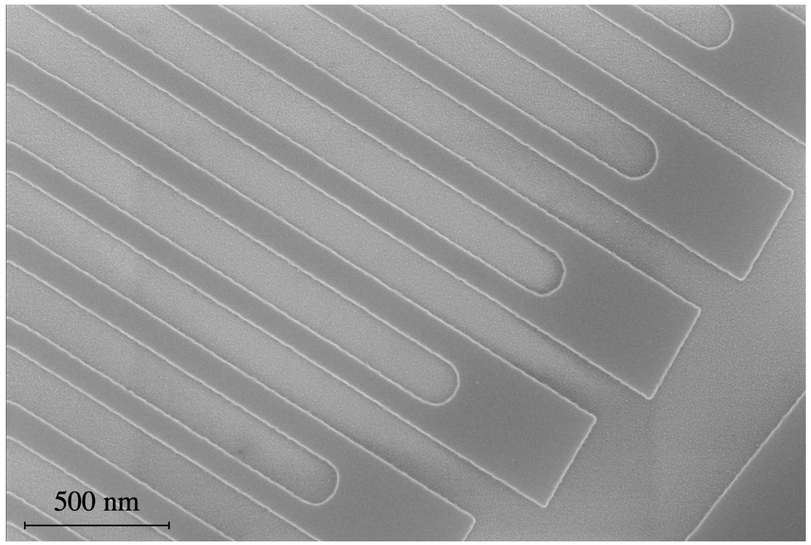
Requires the creation AND storage of entanglement

Solves/addresses problem of distance/loss

N. Sangouard *et al.*, RMP **83**, 33 (2011)

SNSPD - Superconducting Nanowire Single Photon Detector

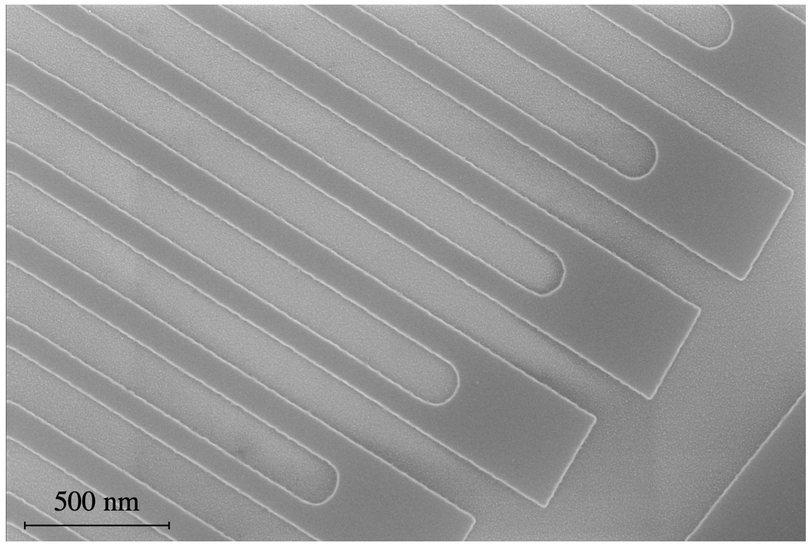
Precision fabrication is key to performance



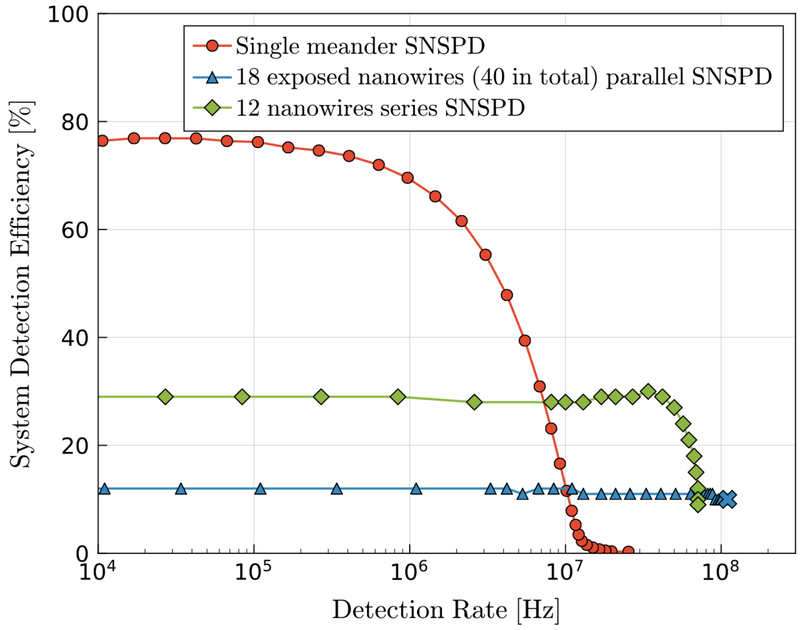
SEM image of the meander after e-beam

SNSPD - Superconducting Nanowire Single Photon Detector

Precision fabrication is key to performance

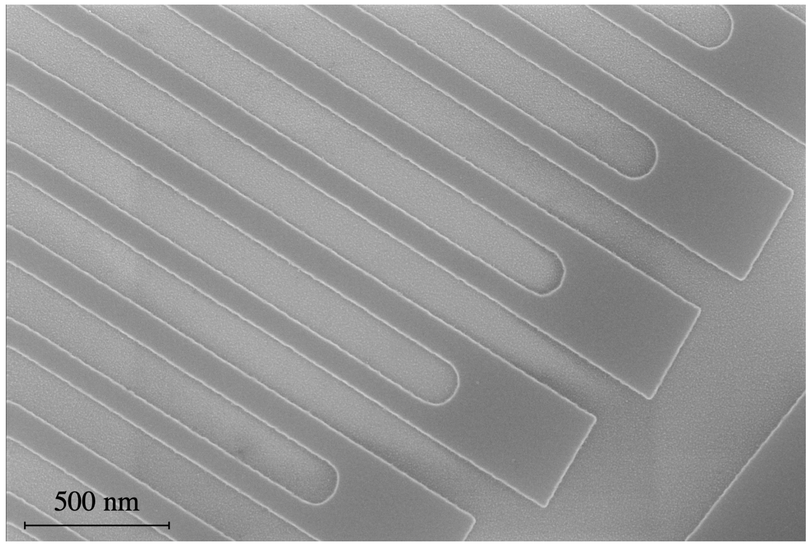


SEM image of the meander after e-beam

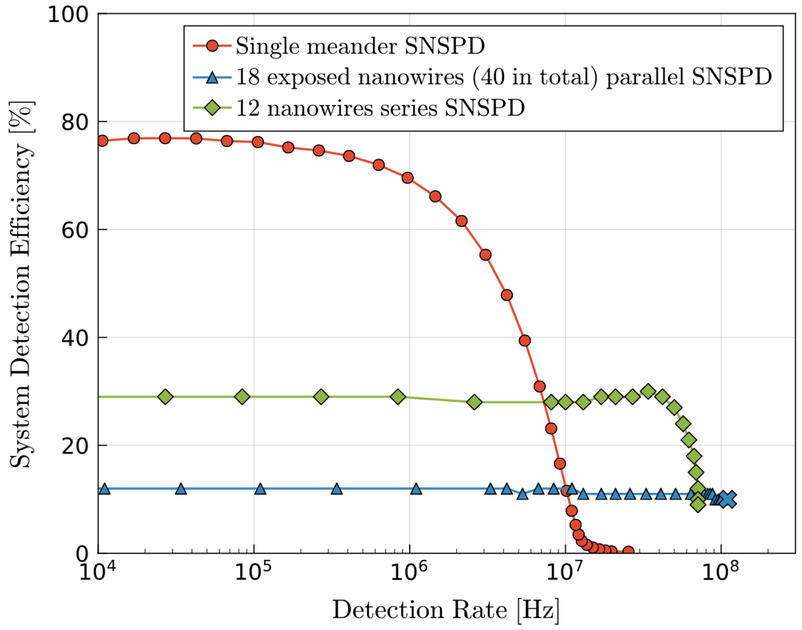


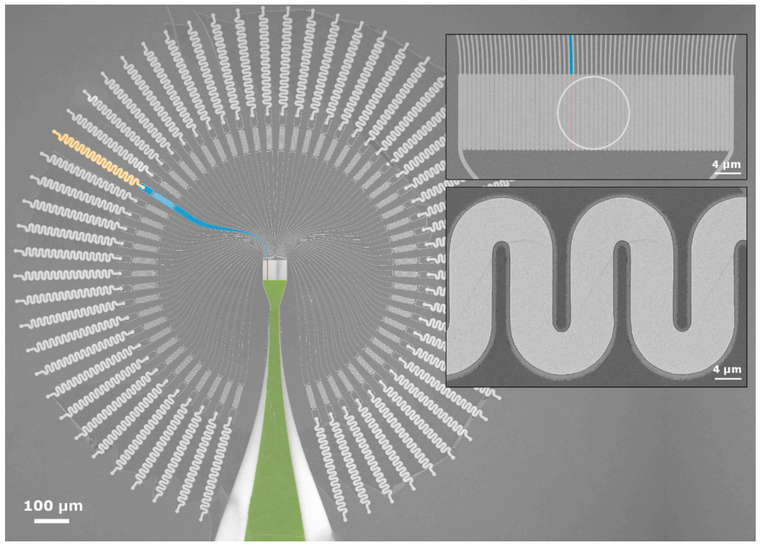
SNSPD - Superconducting Nanowire Single Photon Detector

Precision fabrication is key to performance



SEM image of the meander after e-beam

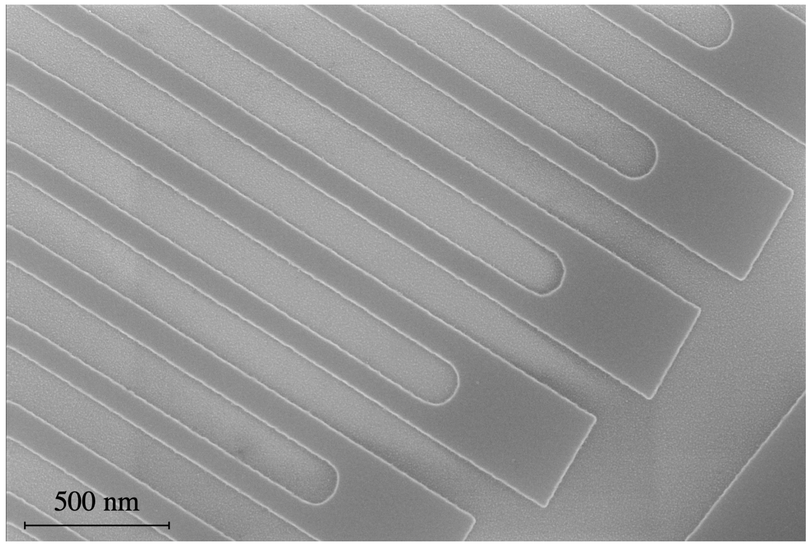




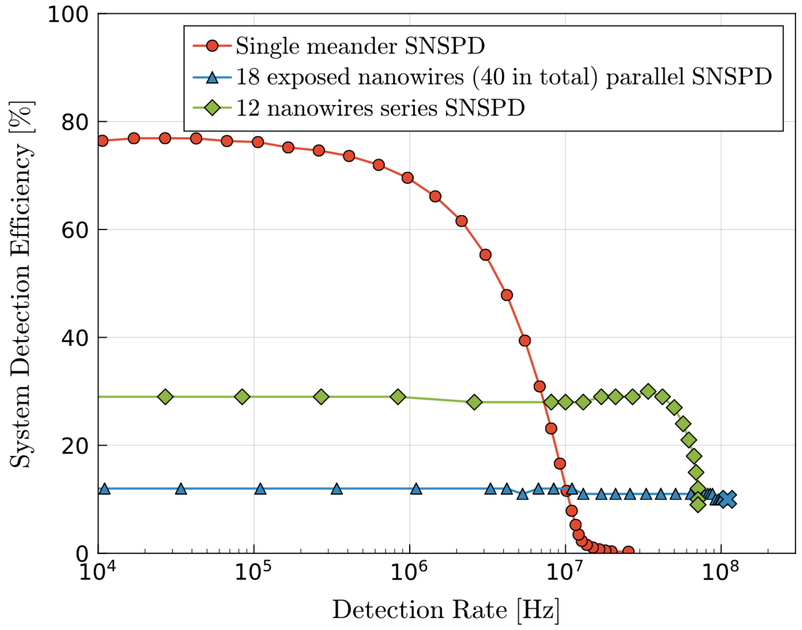
SEM image of 60 parallel nanowire

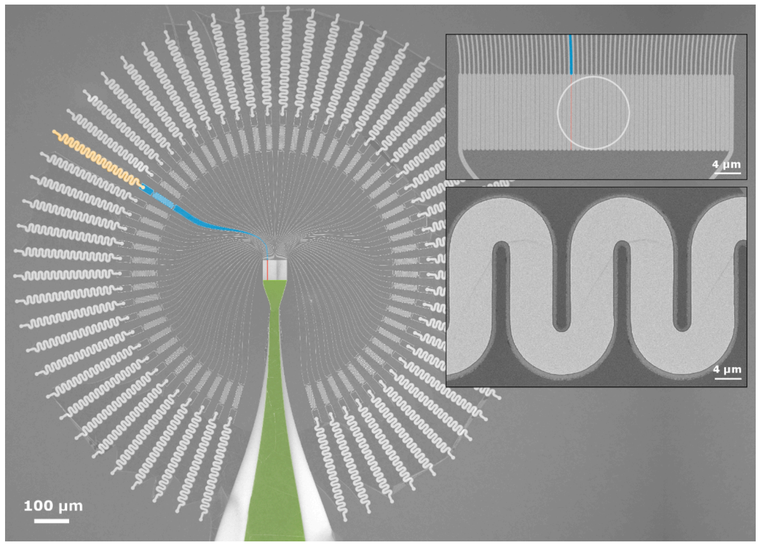
SNSPD - Superconducting Nanowire Single Photon Detector

Precision fabrication is key to performance



SEM image of the meander after e-beam





SEM image of 60 parallel nanowire

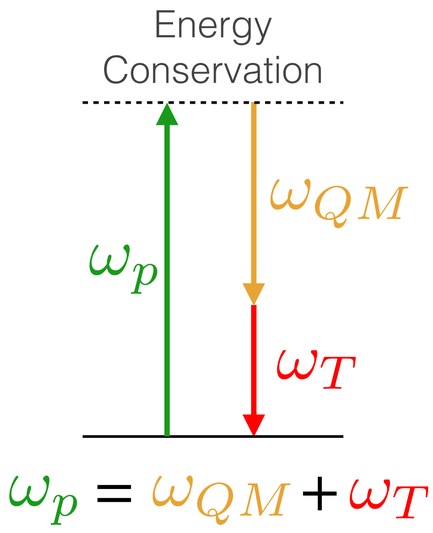
Different materials

Broad wavelength range

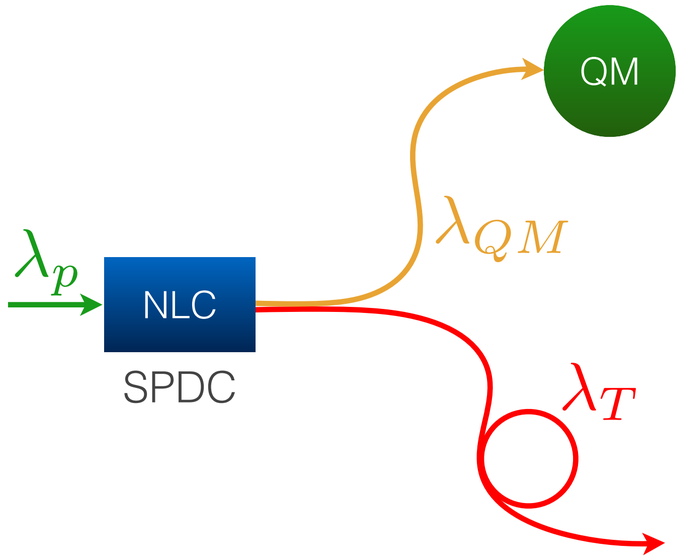
High efficiency, low noise, low jitter

Photon number resolving, high count rates

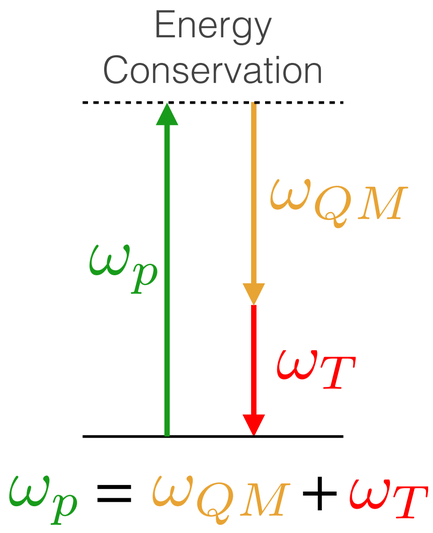
Nonlinear Frequency Conversion



SPDC: Spontaneous Parametric Downconversion

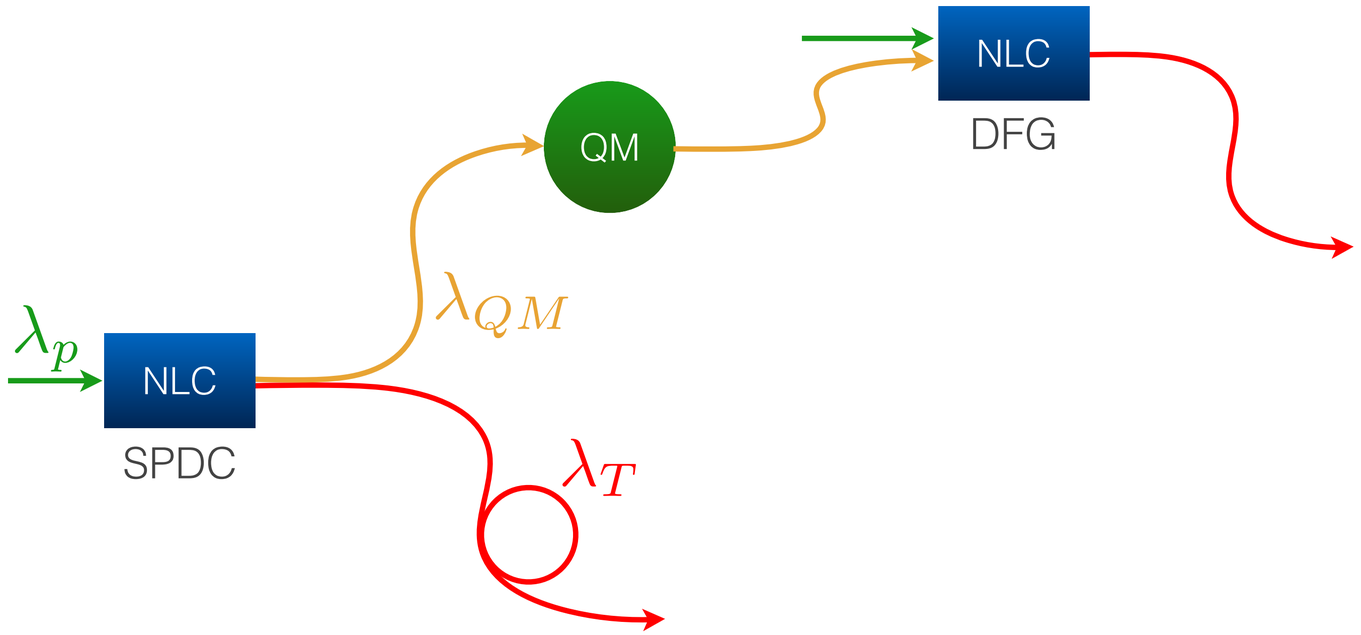


Nonlinear Frequency Conversion

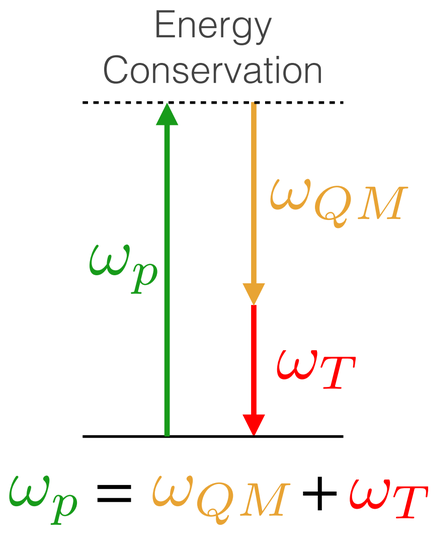


SPDC: Spontaneous Parametric Downconversion

DFG: Difference-Frequency Generation



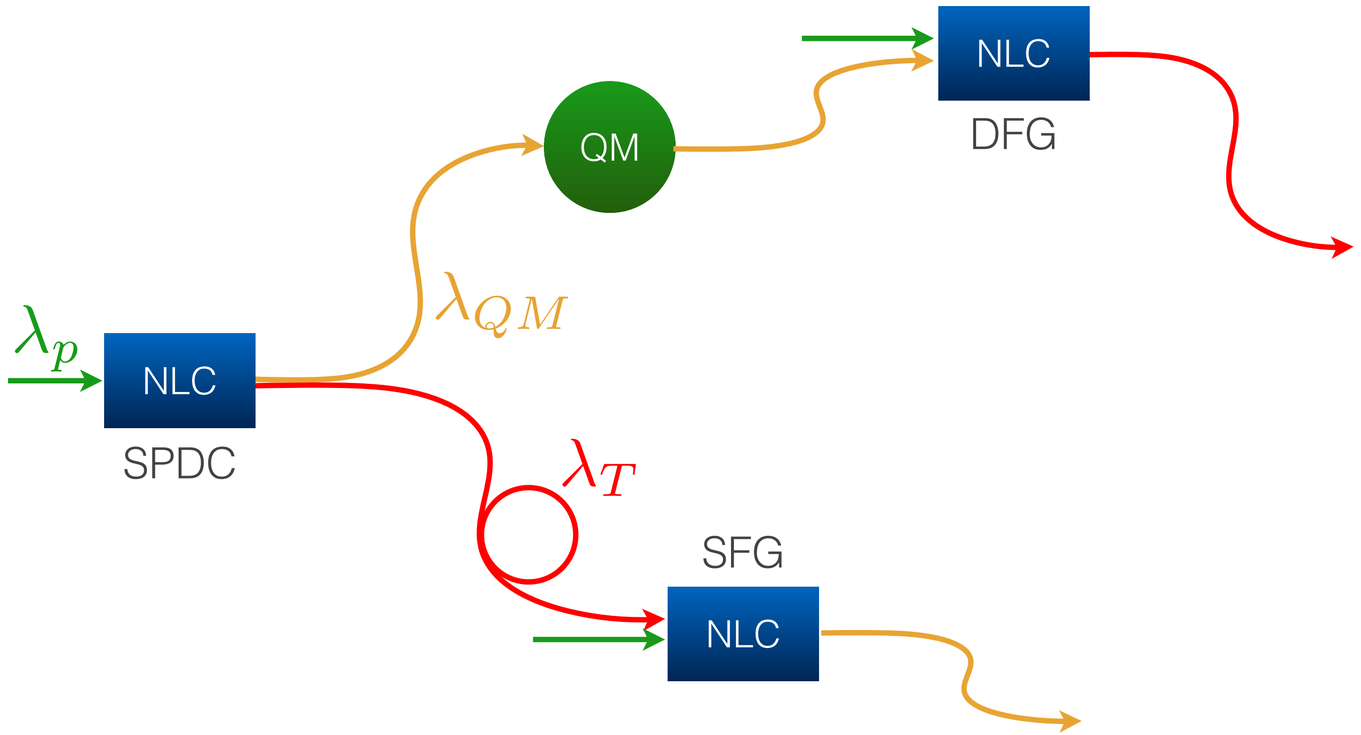
Nonlinear Frequency Conversion



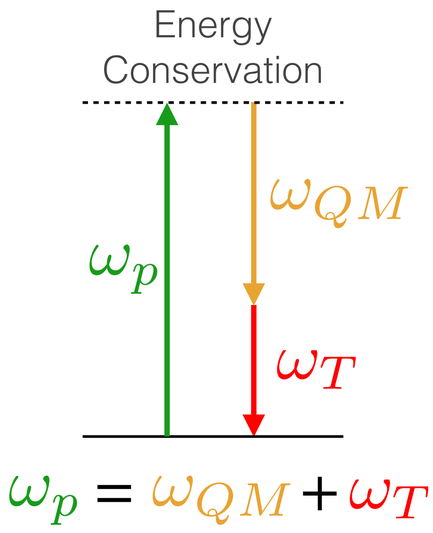
SPDC: Spontaneous Parametric Downconversion

DFG: Difference-Frequency Generation

SFG: Sum-Frequency Generation



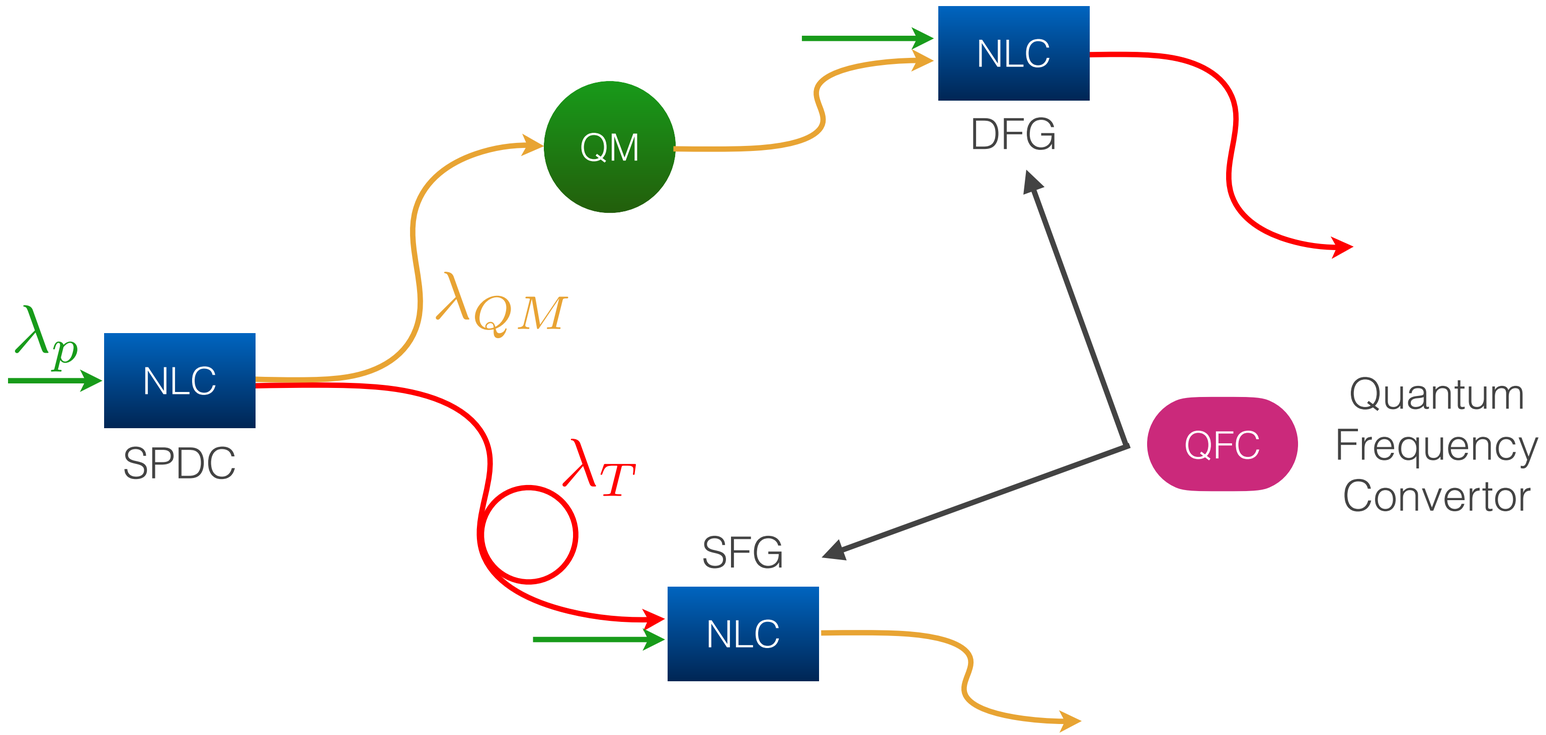
Nonlinear Frequency Conversion



SPDC: Spontaneous Parametric Downconversion

DFG: Difference-Frequency Generation

SFG: Sum-Frequency Generation



Nonlinear Frequency Conversion

$\chi^{(2)}$

Energy Conservation

ω_p ω_{QM} ω_T

$\omega_p = \omega_{QM} + \omega_T$

SPDC: Spontaneous Parametric Downconversion

DFG: Difference-Frequency Generation

SFG: Sum-Frequency Generation

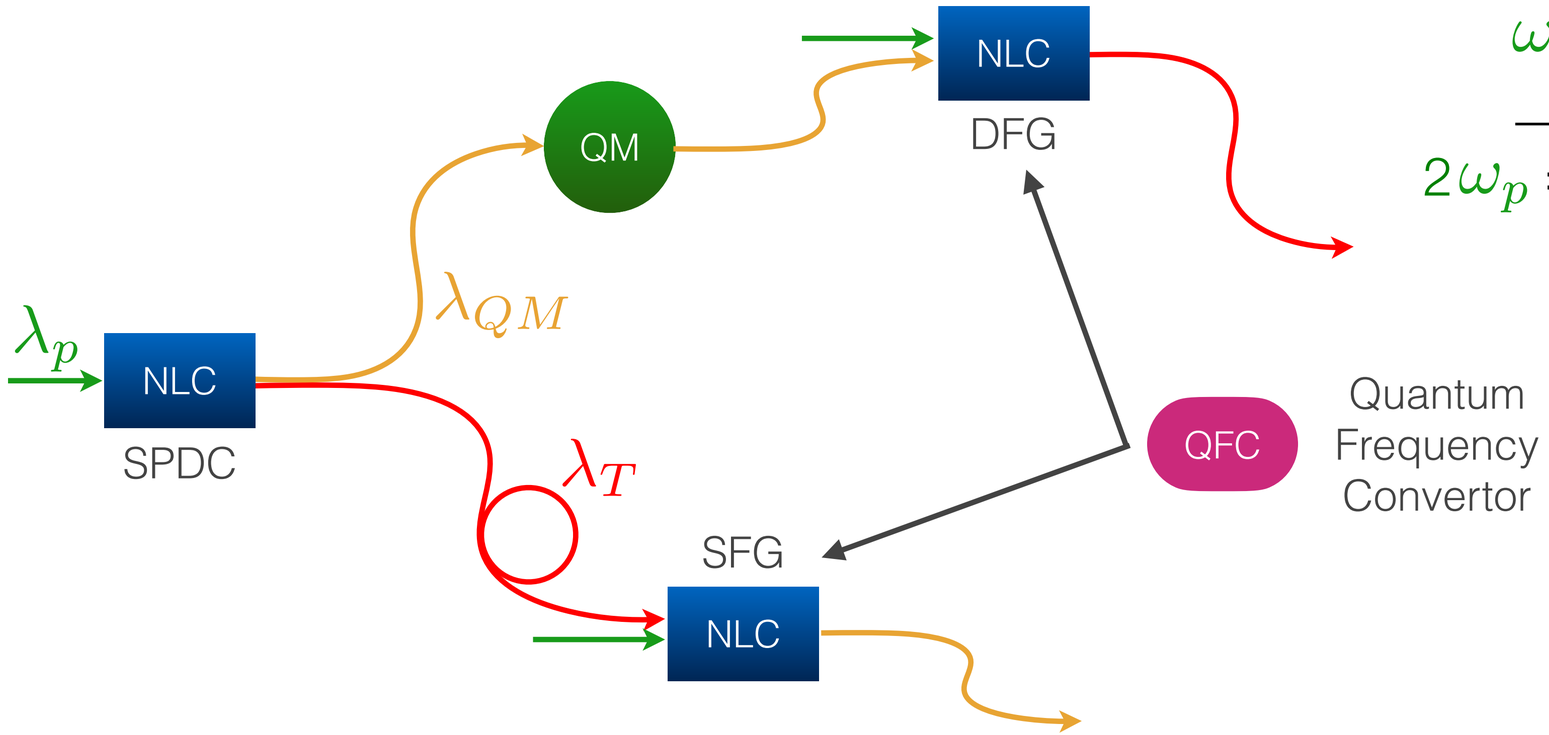
$\chi^{(3)}$

Four-Wave Mixing

Energy Conservation

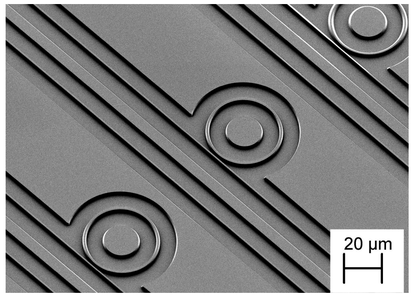
ω_p ω_{QM} ω_p ω_T

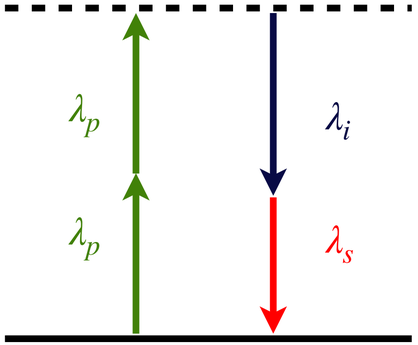
$2\omega_p = \omega_{QM} + \omega_T$

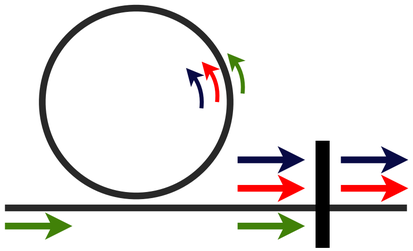


Silicon Nitride (SiN) Micro-Ring Resonators

Silicon Nitride (SiN) Micro-Ring Resonators

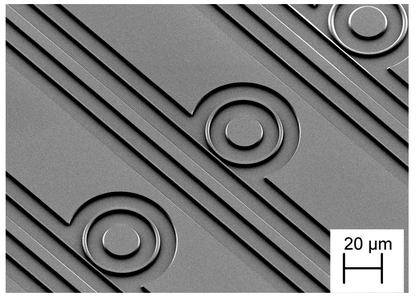


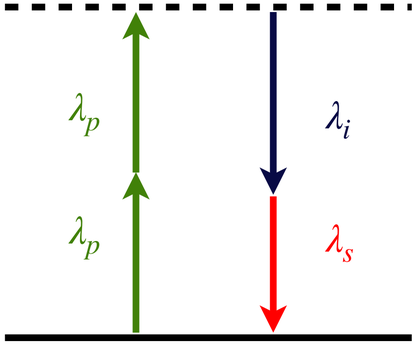


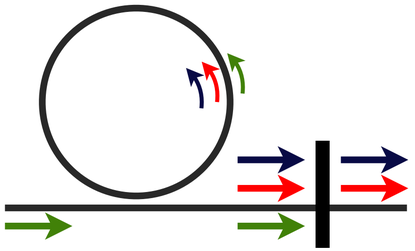


CMOS compatible Fabrication.
No (Low) Two Photon Absorption.

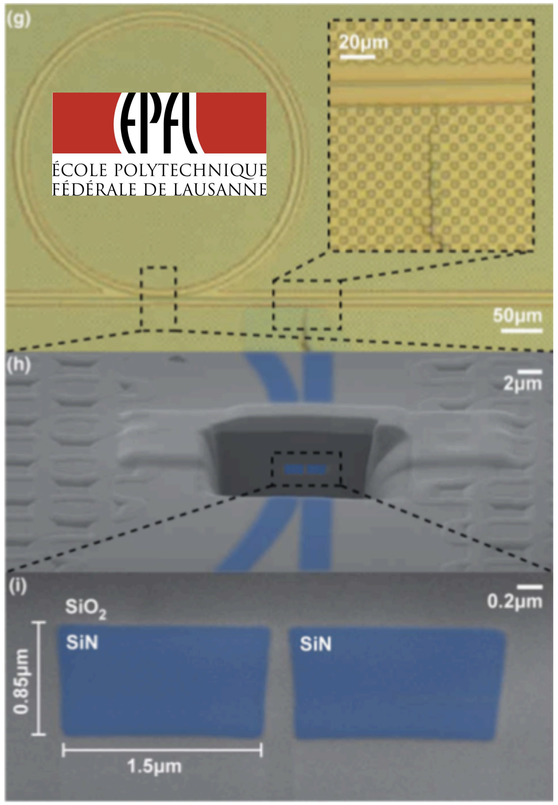
Silicon Nitride (SiN) Micro-Ring Resonators







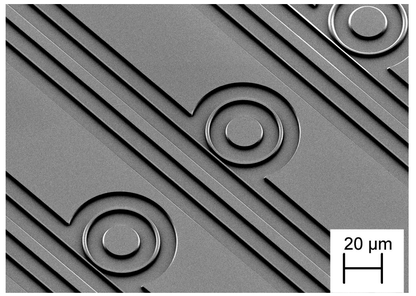
CMOS compatible
Fabrication.
No (Low) Two Photon
Absorption.

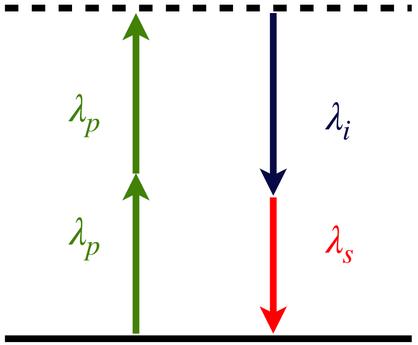


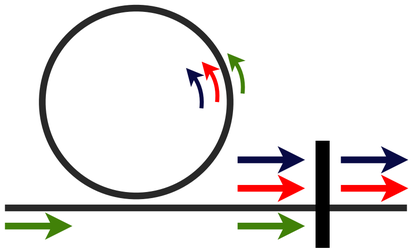
Kippenberg Group
Optica., **3** 2334 (2016)

Improved Fabrication
High-Q resonator
Low Loss
Improved coupling

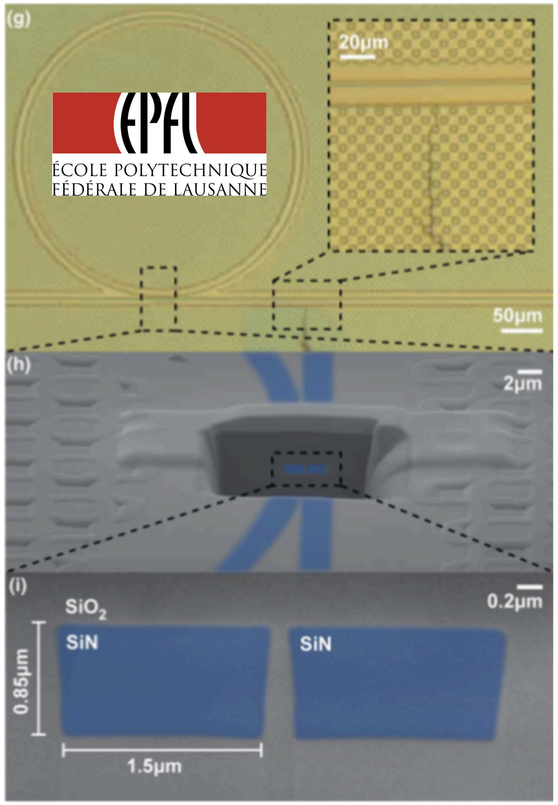
Silicon Nitride (SiN) Micro-Ring Resonators





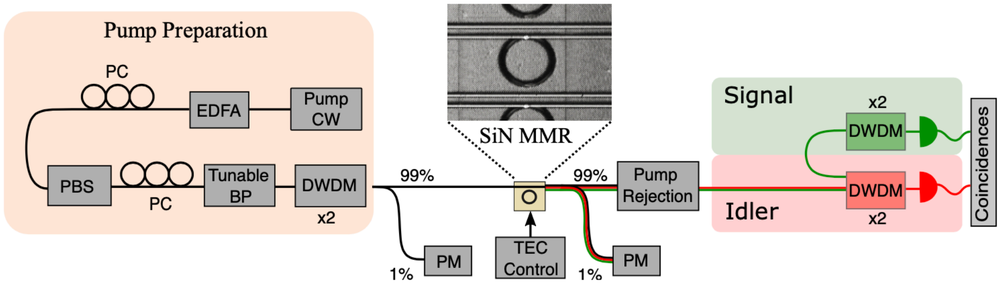


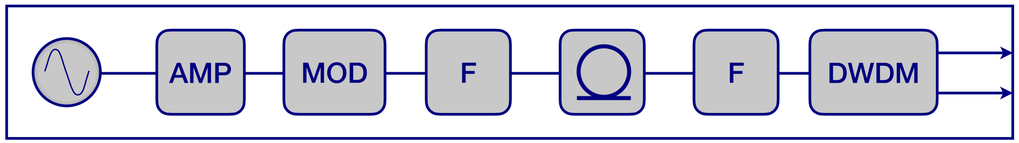
CMOS compatible
Fabrication.
No (Low) Two Photon
Absorption.



Kippenberg Group
Optica., **3** 2334 (2016)

Improved Fabrication
High-Q resonator
Low Loss
Improved coupling





All telecom compatible,
all fibre, all in a box/rack/chip(?)

Continuous wave &
Pulsed (Tuneable repetition rates)

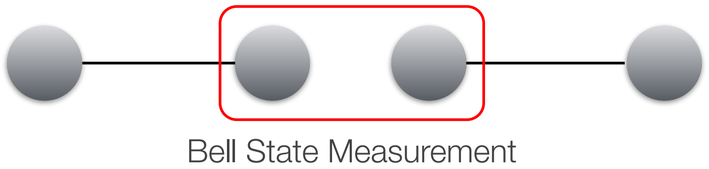
F. Samara, *et al.*,
Opt. Exp., **27** 19309 (2019)

Quantum Repeaters - Entanglement Swapping

Teleporting Entanglement

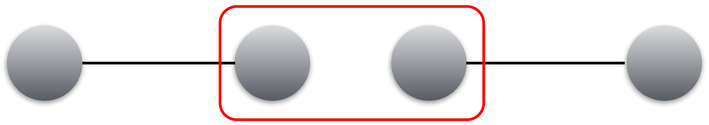
Quantum Repeaters - Entanglement Swapping

Teleporting Entanglement

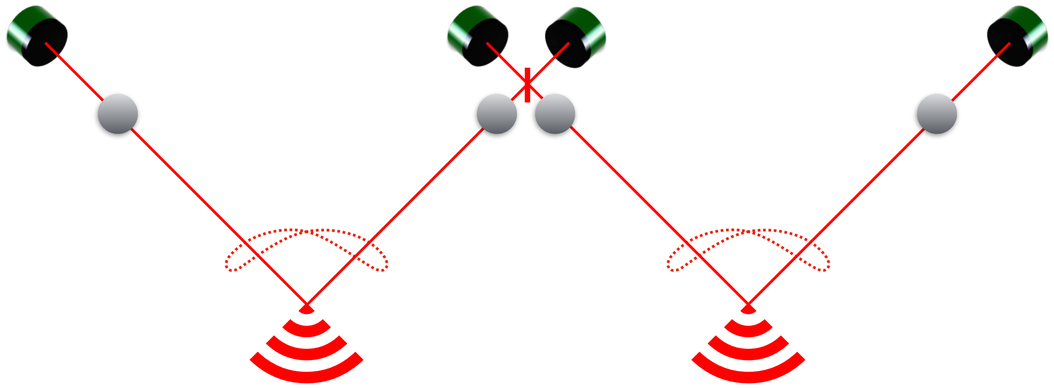


Quantum Repeaters - Entanglement Swapping

Teleporting Entanglement



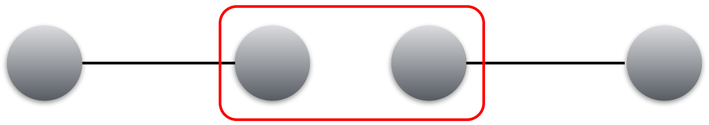
Bell State Measurement



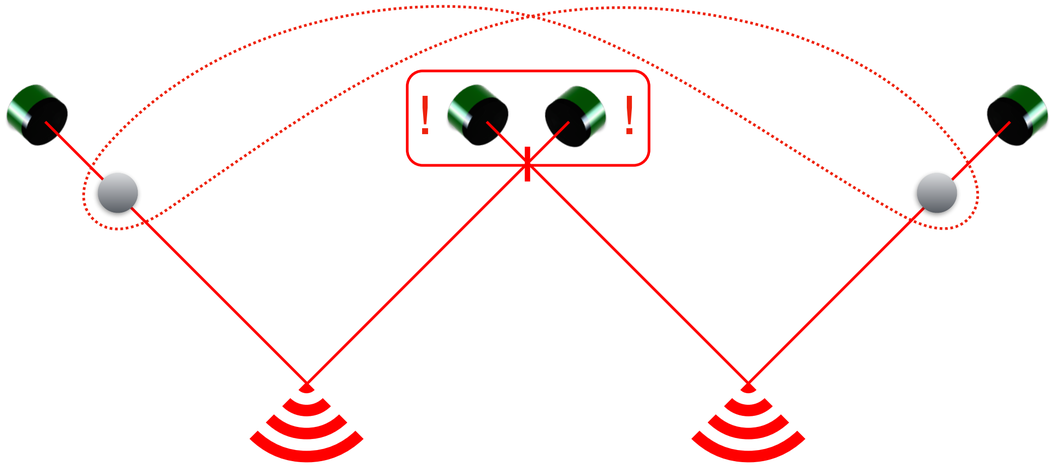
Independent Photon Pair Sources

Quantum Repeaters - Entanglement Swapping

Teleporting Entanglement



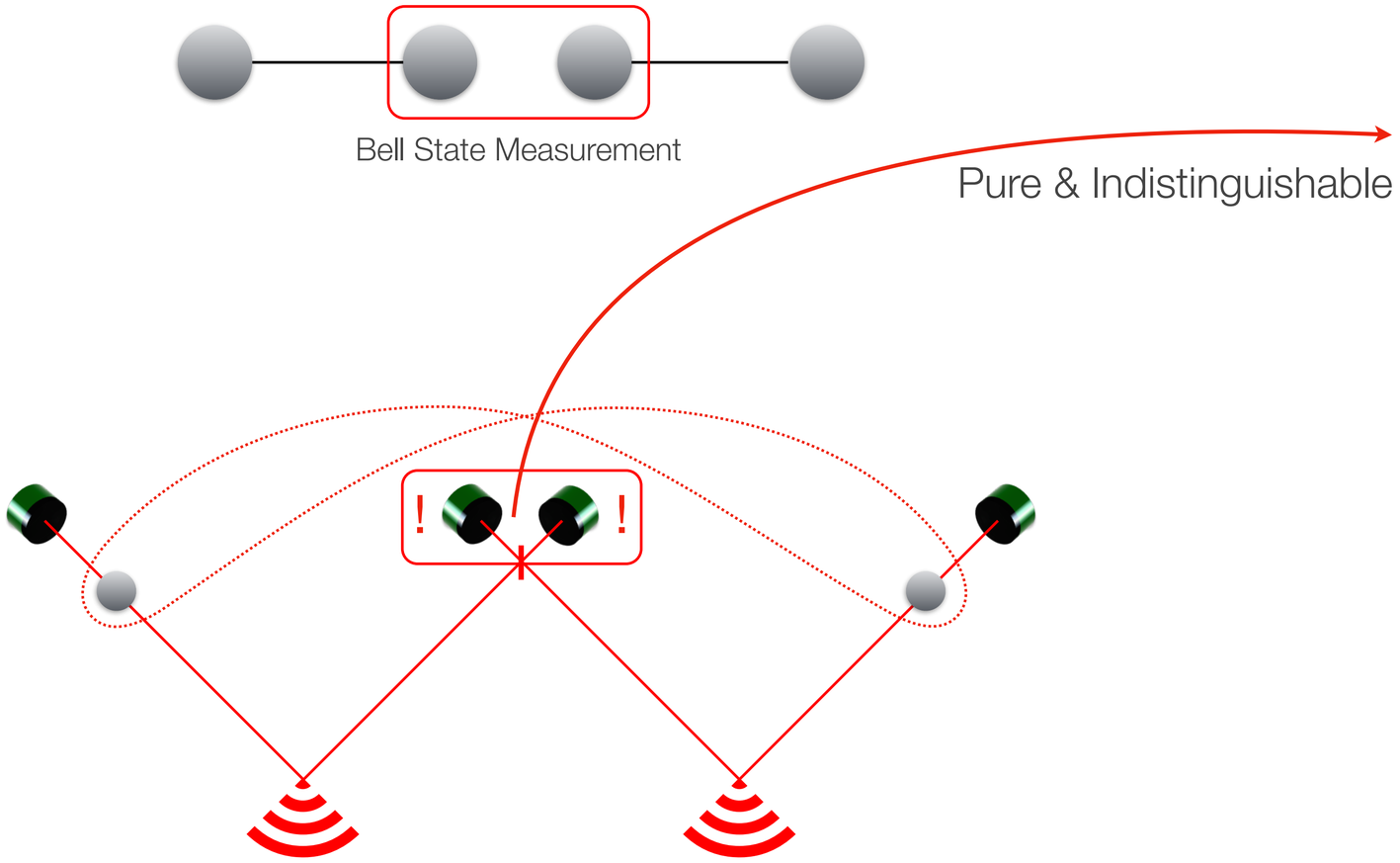
Bell State Measurement



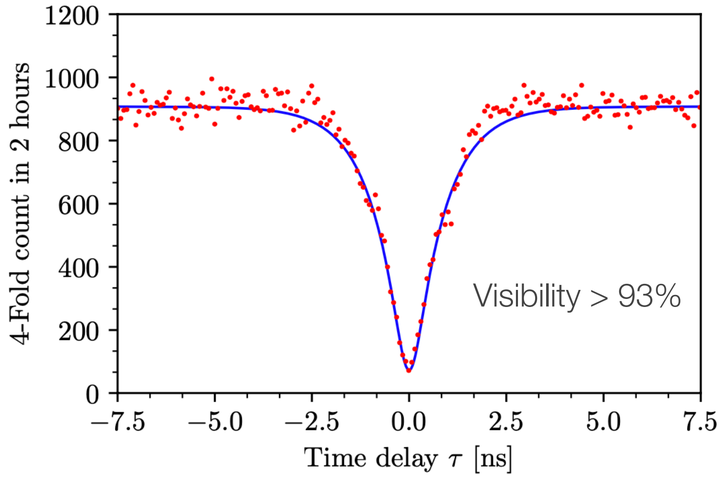
Independent Photon Pair Sources

Quantum Repeaters - Entanglement Swapping

Teleporting Entanglement

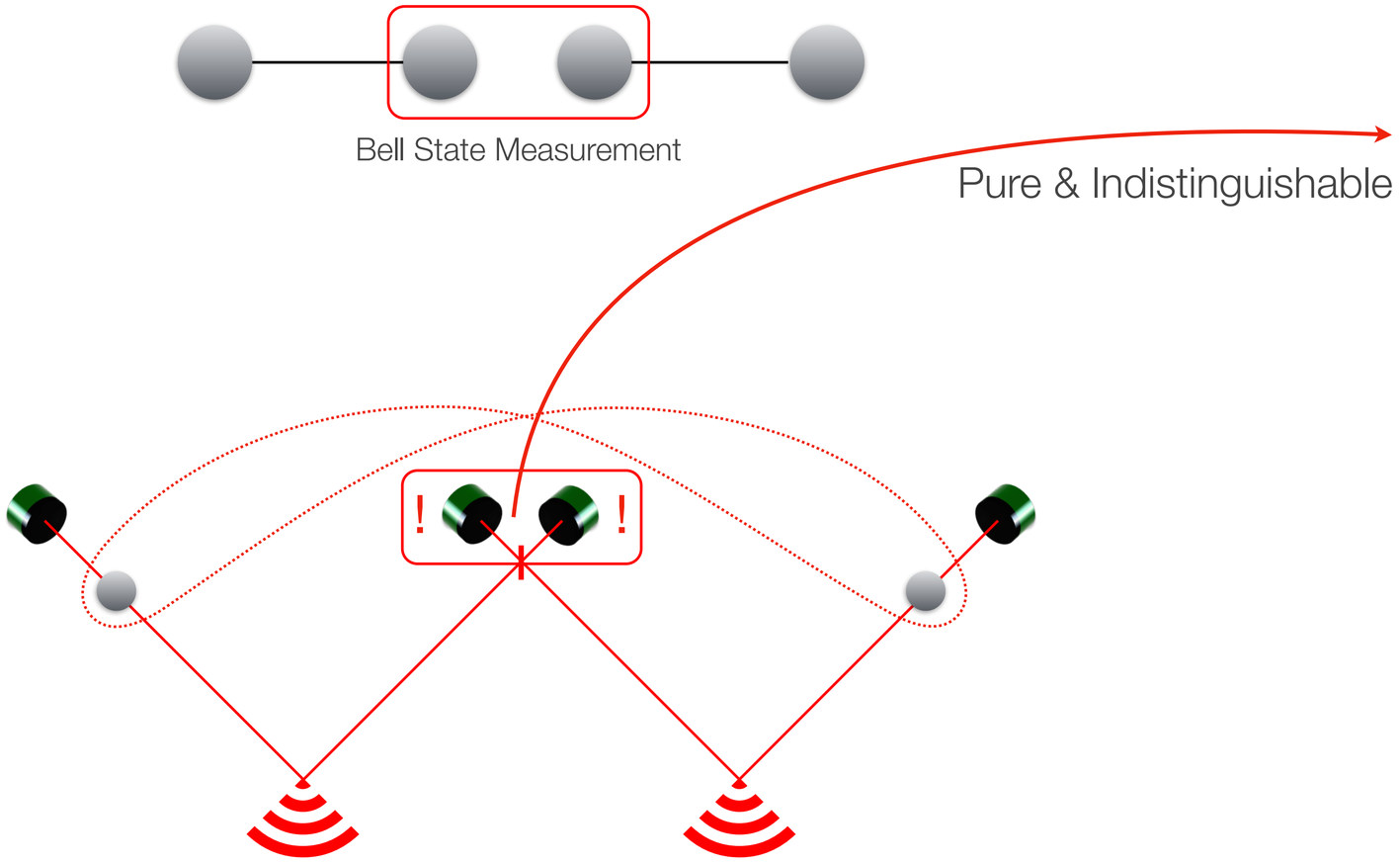


F. Samara *et al.*, Quantum Sci. Technol. **6** 045024 (2021)

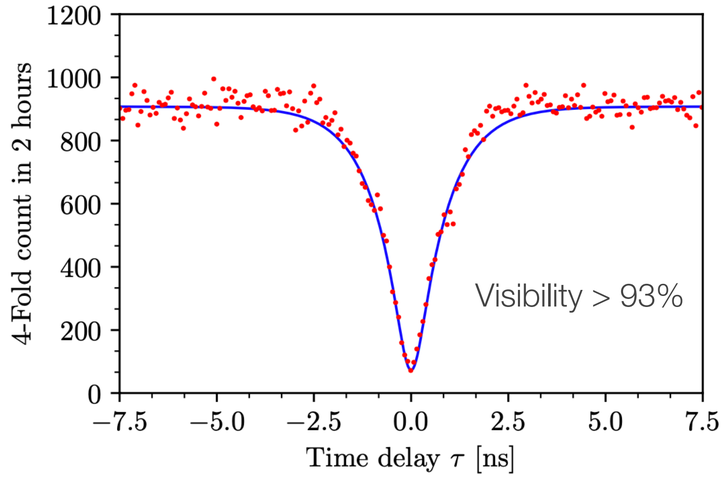


Quantum Repeaters - Entanglement Swapping

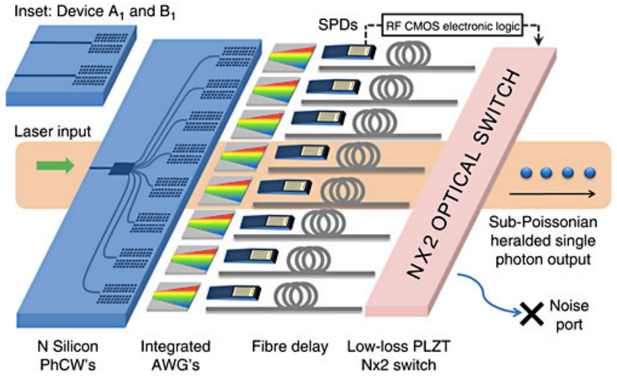
Teleporting Entanglement



F. Samara *et al.*, Quantum Sci. Technol. **6** 045024 (2021)



"Quasi-Deterministic Photon Source"



Multiplexed Sources + Integrated Photonics

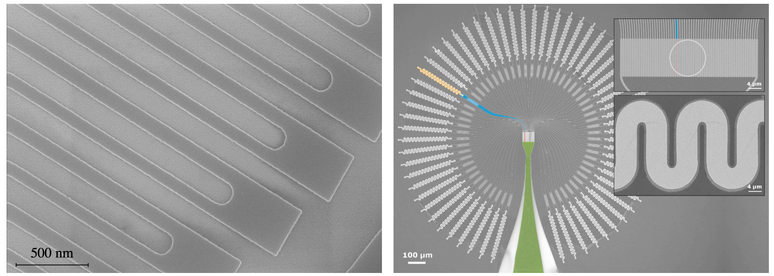
Eggleton *et al.*, Nature Comm. **4**, 2582 (2013)

UNIVERSITÉ
DE GENÈVE

What did we just see?

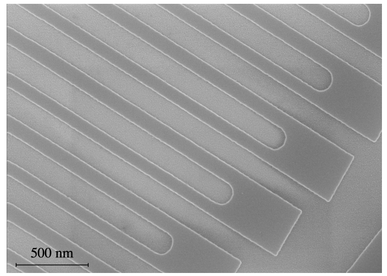
What did we just see?

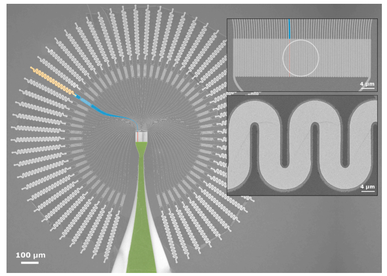
Single Photon Detection



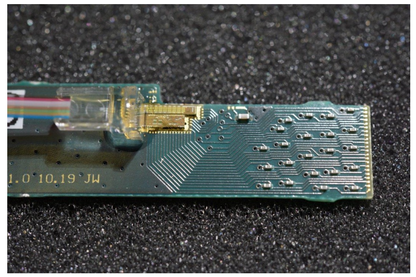
What did we just see?

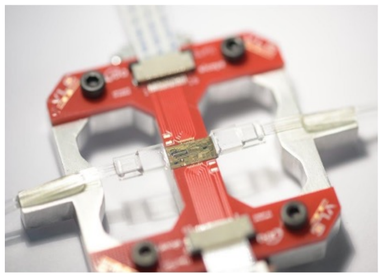
Single Photon Detection

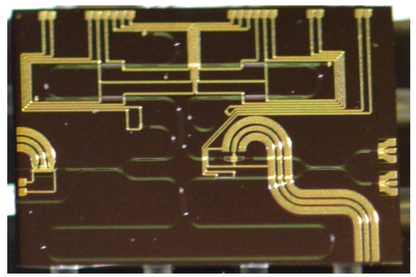


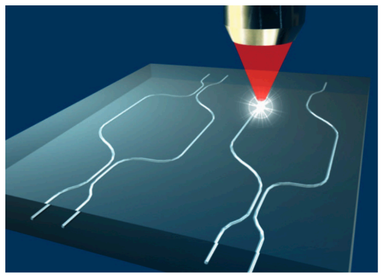


QRNG & QKD



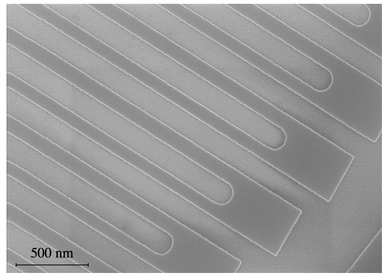


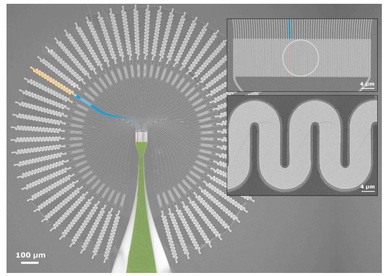




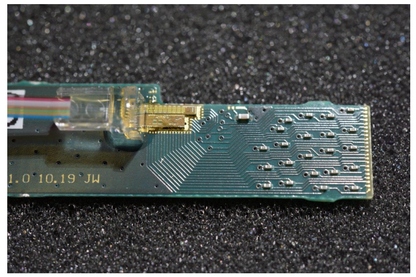
What did we just see?

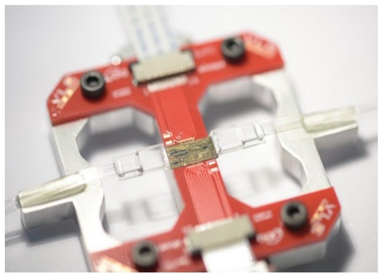
Single Photon Detection

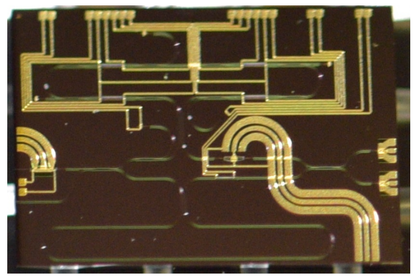


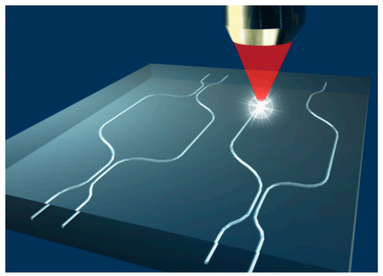


QRNG & QKD

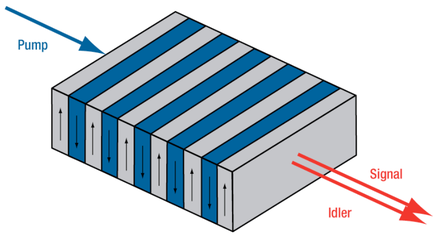


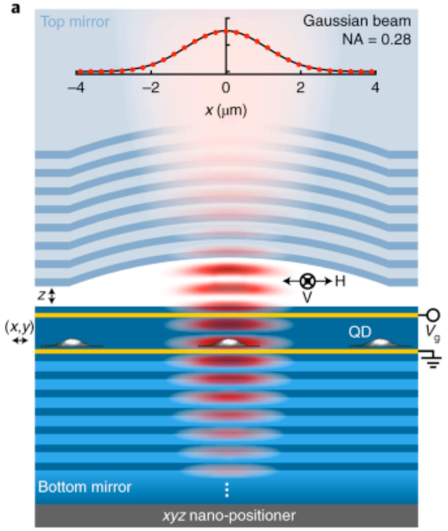


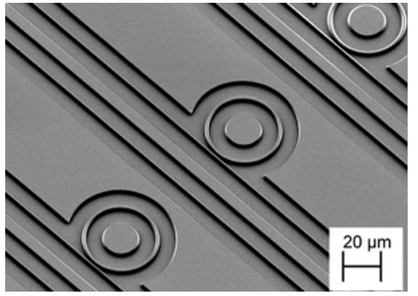


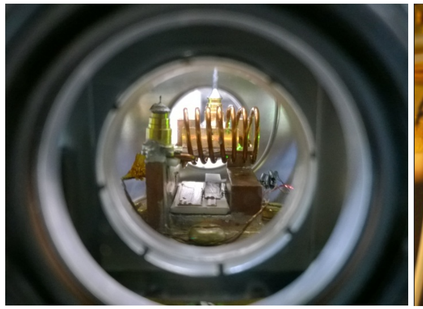


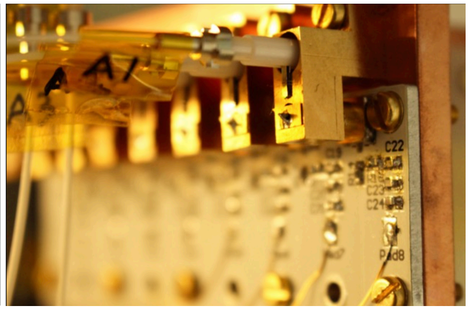
Entanglement-Based Quantum Communication







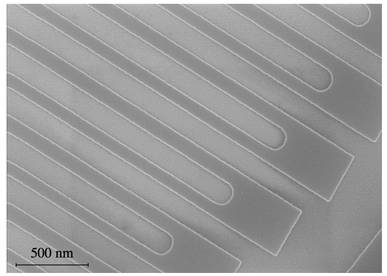


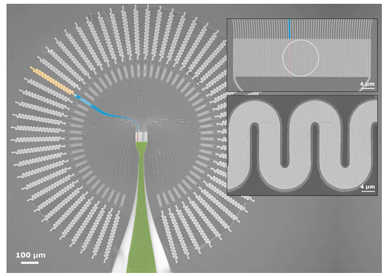


UNIVERSITÉ DE GENÈVE

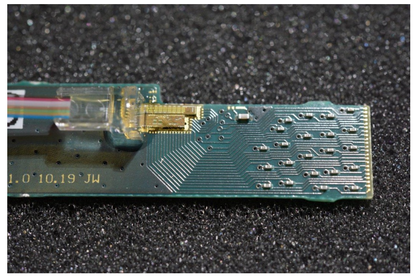
What did we just see? A lot of photonic challenges & possibilities!

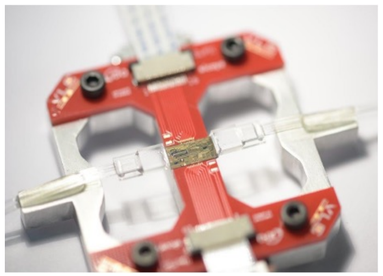
Single Photon Detection

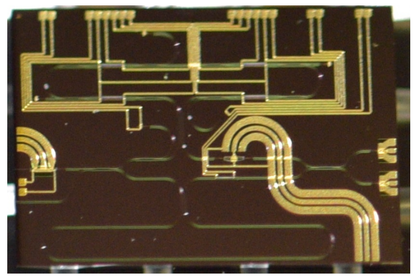


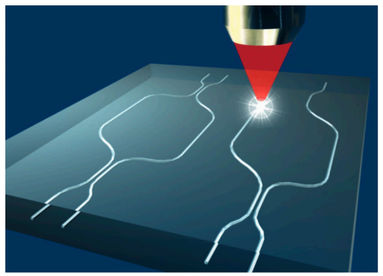


QRNG & QKD









Entanglement-Based Quantum Communication