From Lab to Fab: Expanding Quantum Frontiers with Superconducting Single-Photon Detectors

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ID Quantique SA

28th October 2021

The value of Quantum Technologies

Quantum technologies are set to revolutionize the world we live in.

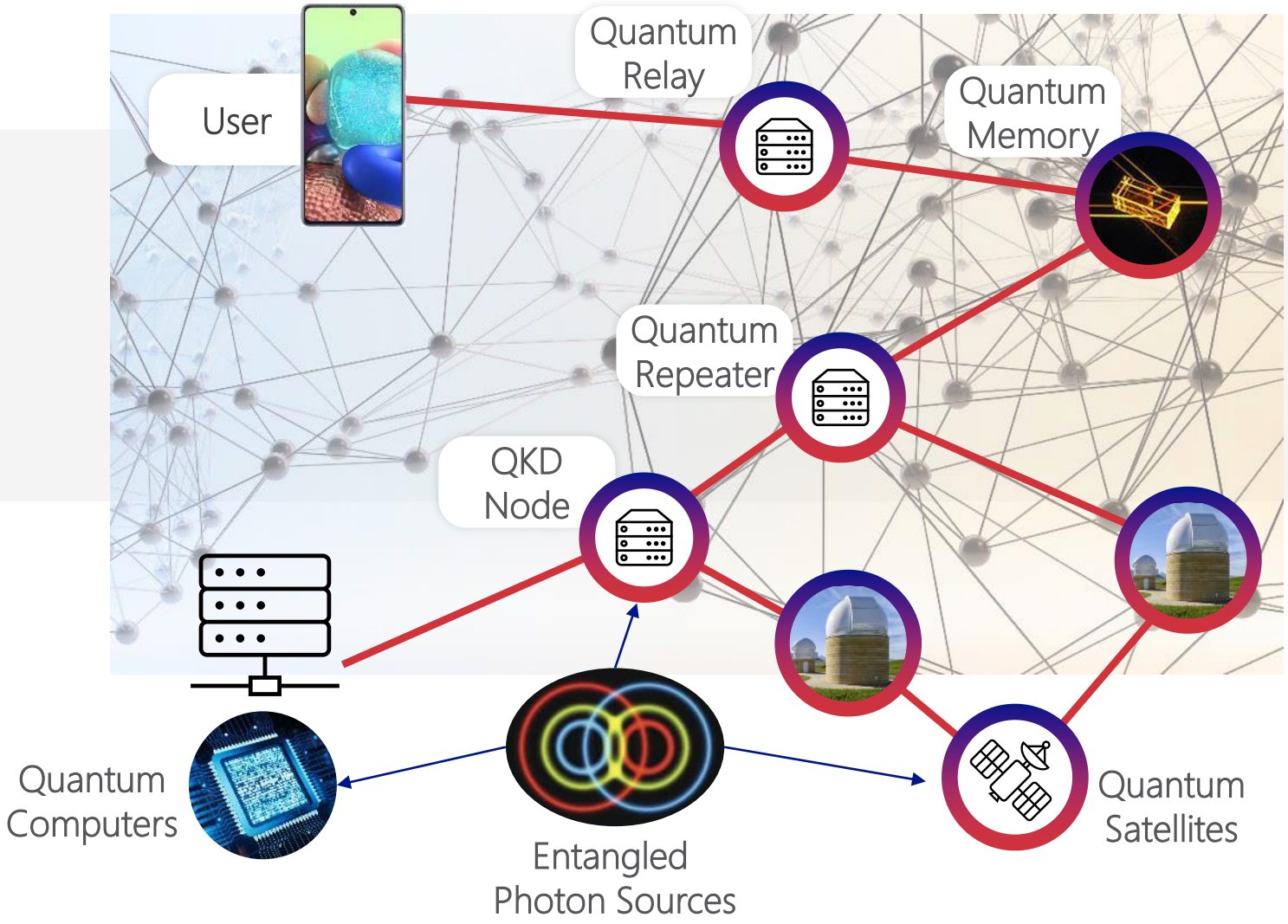
Quantum technologies

- Quantum Sensing
- Quantum Communications
- Quantum Computing

- Energy
- Industrial Goods
- High Tech
- Chemistry & Pharma
- Finance
- Public Safety

But will also break keys!

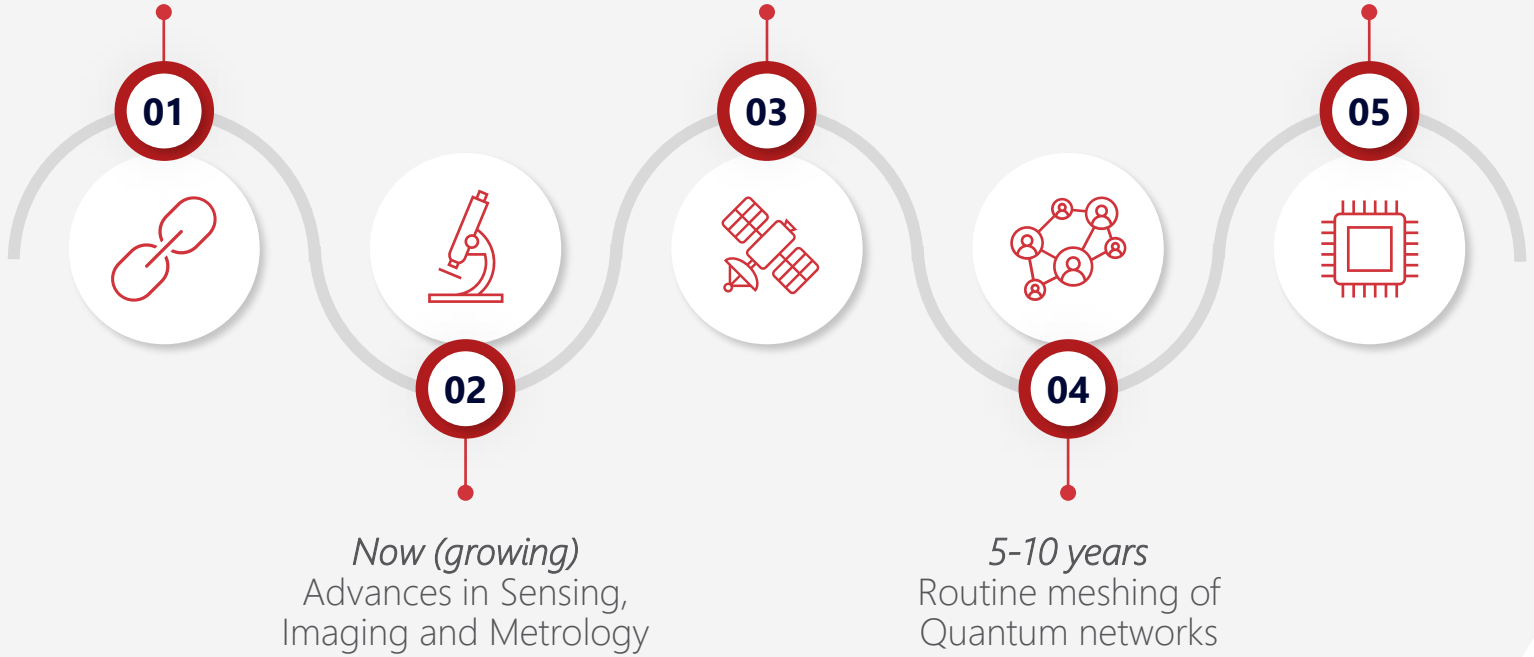
Towards the Quantum Internet



Connecting global quantum devices with photons

Towards the Quantum Internet

Quantum technologies are set to revolutionize the world we live in.



IDQ's Quantum Sensing technologies & products

Enabling Quantum Technology through Photonic Sensing Solutions

Low-light level sensing

SPADs

SNSPDs

Time resolved single-photon detection

Precision timing & control

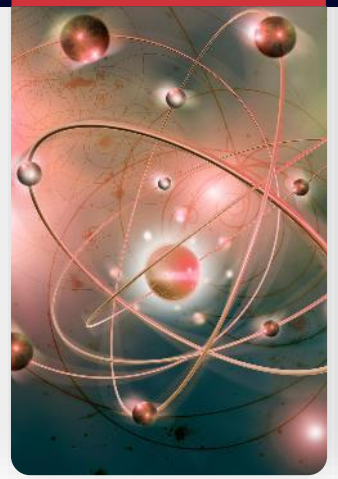
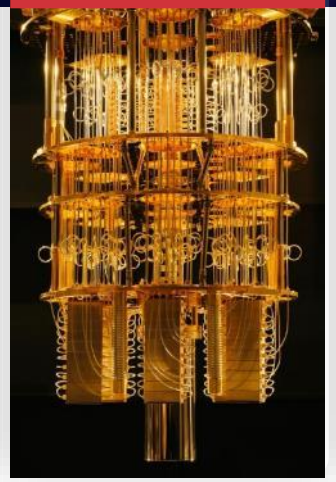
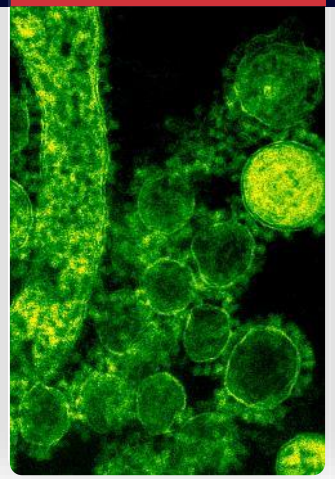
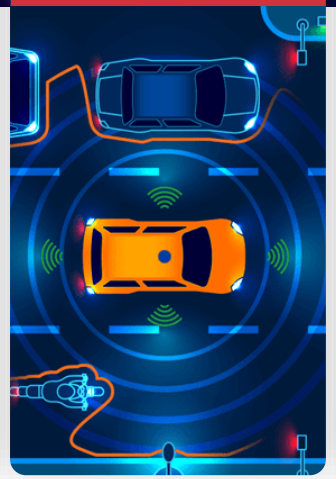
Time Controller

Pulsed Lasers

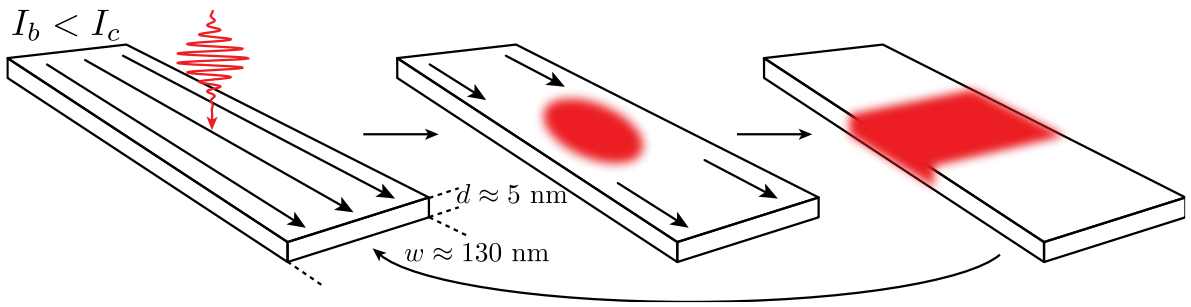
IDQ's Quantum Sensing applications

Time-Resolved Single-Photon detection

- Combining single-photon detection with Time-Tagging and TCSPC electronics
- Enable new applications in a variety of domains
- Enhanced performance: beyond conventional sensing techniques

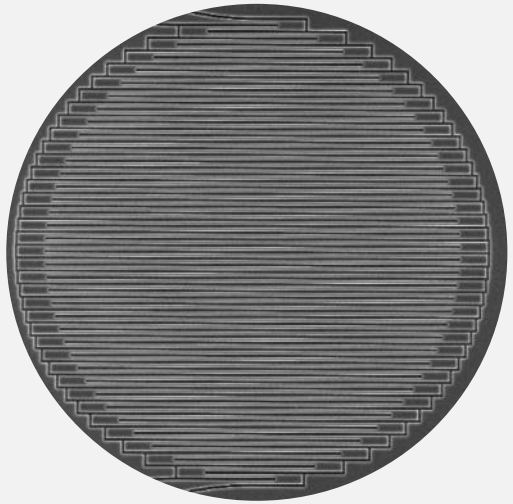
Quantum physics	Communication	Quantum Computing	Material science	Life science	OTDR & LIDAR	Defence & Surveillance
						

Superconducting nano(wire/strip) single-photon detectors (SNSPD)



SNSPDs can offer

Free-running operation: No need for synchronization
High efficiency: 95% and above
Low noise (dark counts): from < 1 cps to <100 cps
Low jitter: < Several tens of ps
Short recovery time: > Tens of MHz



ID281 system

Cryogenic amplifiers at 40 K

Fibre-coupled SNSPDs

Upside!

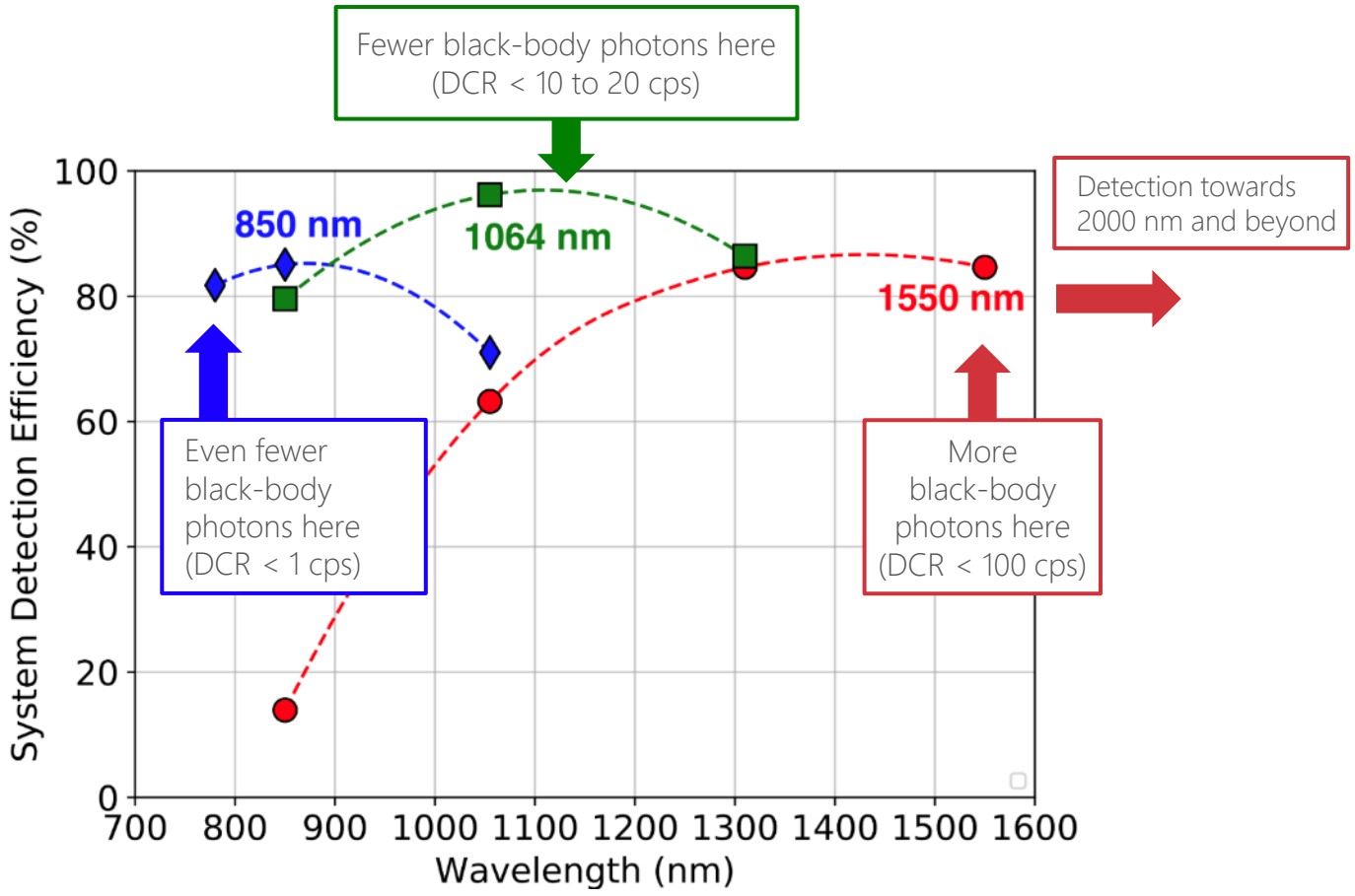
Broadband efficiency: High efficiency over hundreds of nm
Multiple channels: Up to 16 detectors in one system

A turn-key quantum internet enabling tool

ID281 – Broadband efficiency

Broadband efficiency

- **IDQ SNSPDs have intrinsic broadband efficiency**
- **Several optimized wavelength ranges available**
- **Detection beyond 1550 nm or below 780 nm** is possible on demand.



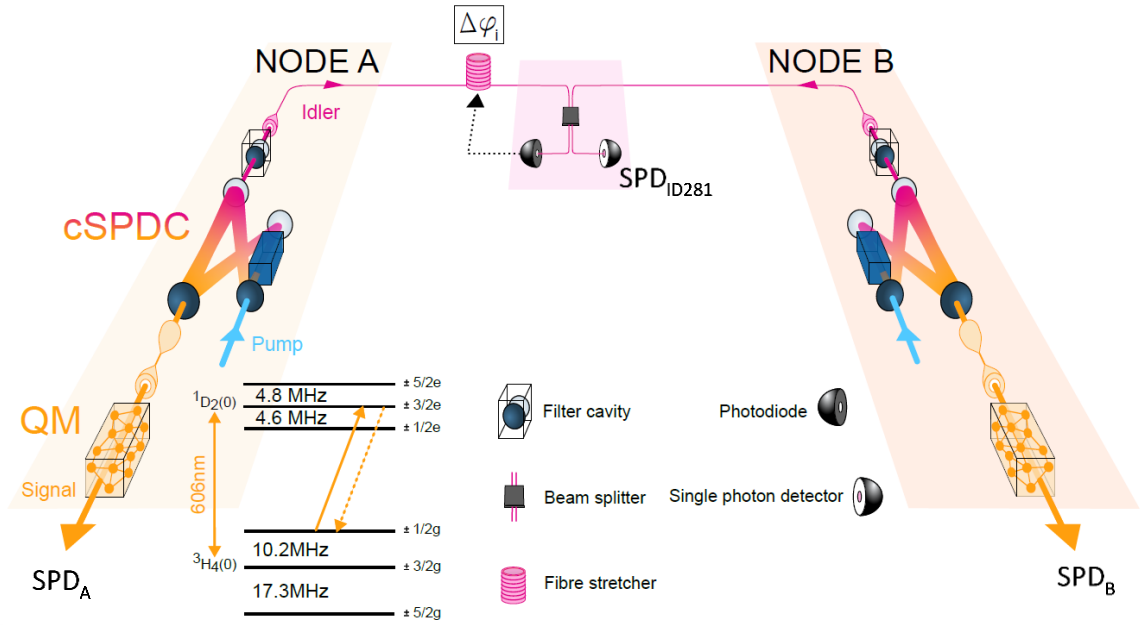
Towards a Quantum Repeater

Article | Published: 02 June 2021

Telecom-heralded entanglement between multimode solid-state quantum memories

Dario Lago-Rivera, Samuele Grandi, Jelena V. Rakonjac, Alessandro Seri & Hugues de Riedmatten

Nature **594**, 37–40 (2021) | Cite this article



Near-ideal efficiency and noise performance

Towards QKD over 1’000 km

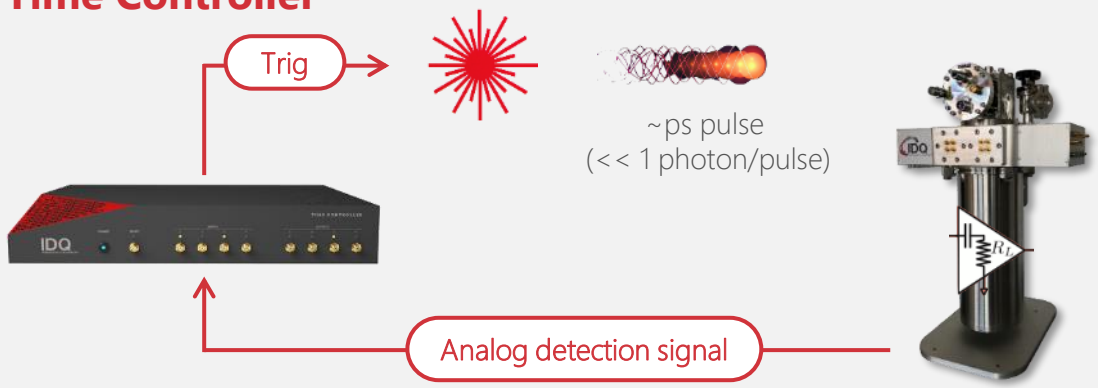
Precise detection for entanglement generation

Successful entanglement of remote quantum memories, and entanglement between a telecom-wavelength photon and an on-demand multimode quantum memory

ID281 SNSPDs with > 80% Quantum efficiency and < 10 Hz Dark Count Rate at 1450 nm

Timing Precision

ID900
Time Controller



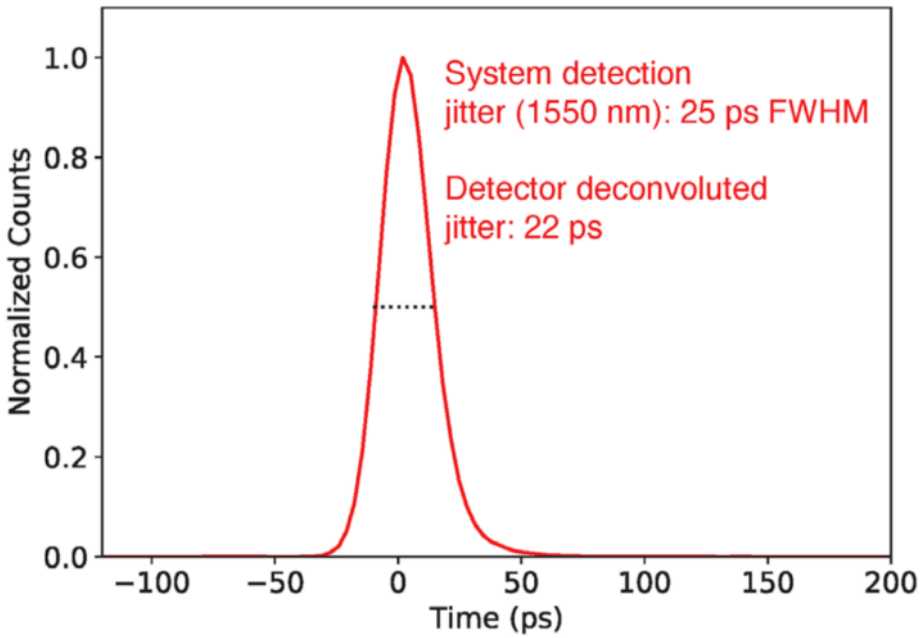
Jitter depends on

- Photon energy: decreases with shorter λ
- Noise in the amplification chain: use cryogenic amplifiers
- Bias current value: needs to be at maximum value (just below the critical current)

Cold preamps are standard in the ID281

Upside: protection from spurious external noise sources

Detector response



On-chip ultra-bright single photon sources

PHYSICAL REVIEW LETTERS

Featured in Physics | Editors' Suggestion

Ultrabright Quantum Photon Sources on Chip

Zhaohui Ma, Jia-Yang Chen, Zhan Li, Chao Tang, Yong Meng Sua, Heng Fan, and Yu-Ping Huang

Phys. Rev. Lett. **125**, 263602 – Published 22 December 2020

Physics See synopsis: Ultrabright Photons for Single-Chip Quantum Devices

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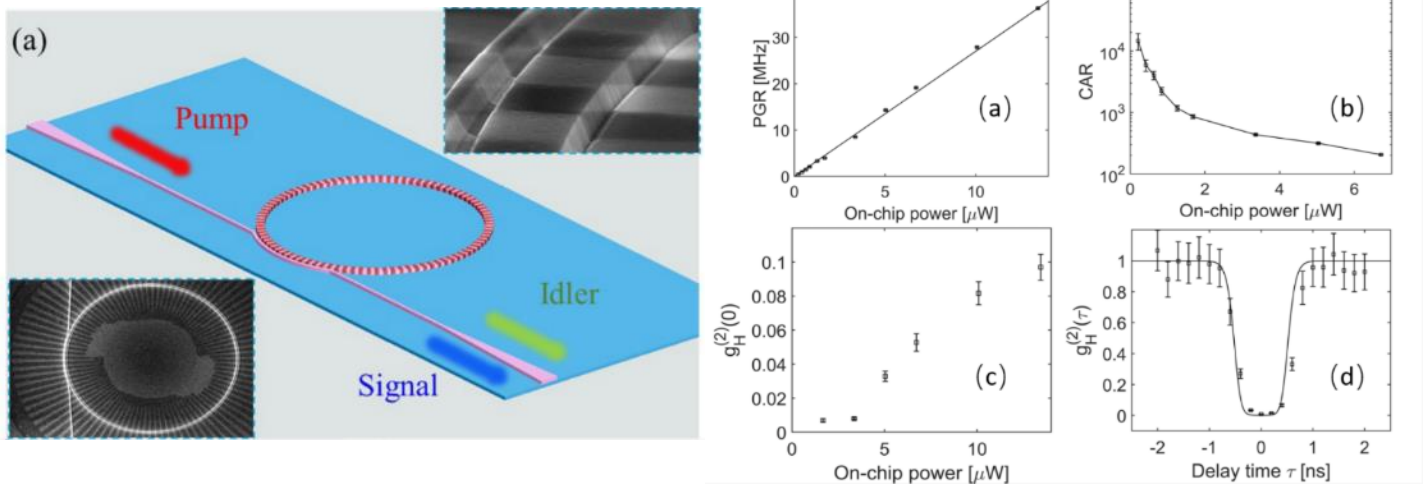


Efficient, low-noise, well-resolved single-photon detection

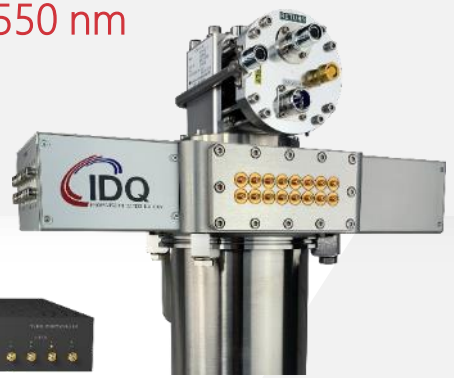
High-fidelity and low-noise ultrabright telecom-wavelength single-photon source

Precise detection for Integrated Quantum Photonics

User Need: To perform ultrafast measurements of the quantum statistics of heralded single-photons, generated by a state-of-the-art on-chip micro-ring resonator.

Solution:

ID281 SNSPDs with
80 to 90% efficiency at 1550 nm
40 Hz Dark Count Rate
<25 ps jitter
paired with the
ID900 Time Controller.

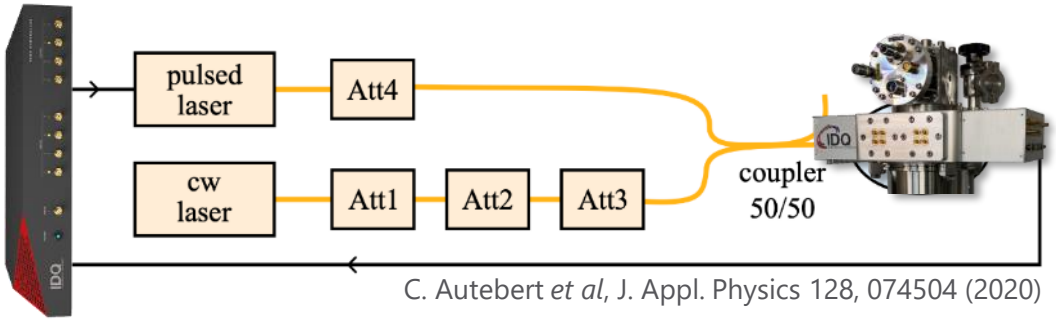


Fast detector recovery

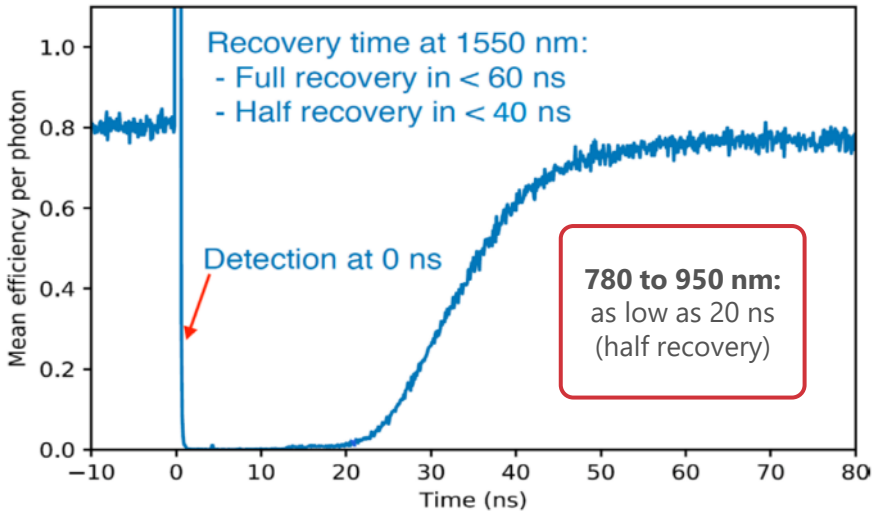
The recovery of the efficiency of SNSPDs

- Follows a sigmoid shape in time
  - that varies from one detector to the other,
  - the shape depends on detector and readout electronics factors
- How it affects your experiment depends on
  - if you measure a continuous or a pulsed photon stream
  - If the detection rate is saturating the detector or not
- Only a full characterization of this sigmoid shape reveals the full impact

The shortest recovery times are obtained with the maximum bias current



C. Autebert *et al*, J. Appl. Physics 128, 074504 (2020)



Pushing the limits of QKD: 420 km with SNSPDs

PHYSICAL REVIEW LETTERS **121,** 190502 (2018)

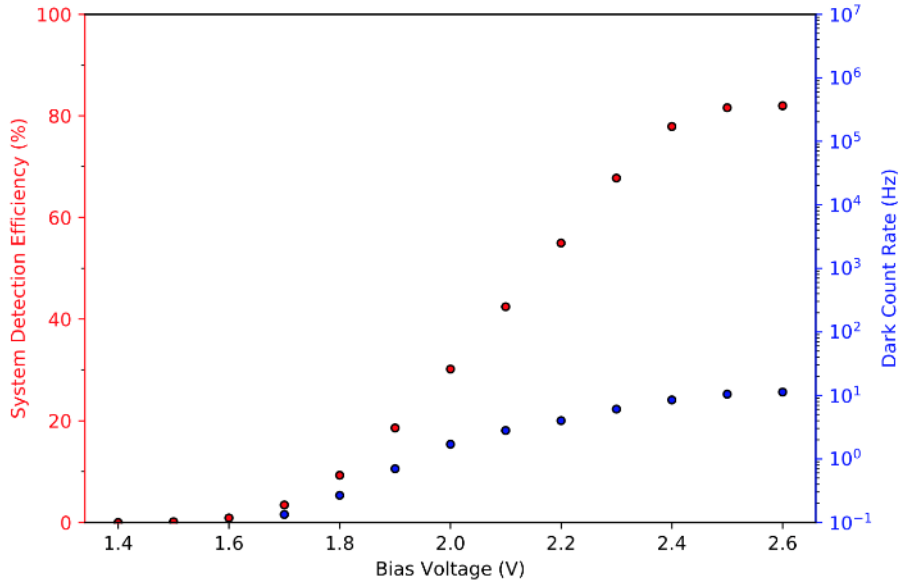
Secure Quantum Key Distribution over 421 km of Optical Fiber

Alberto Boaron,[1,*] Gianluca Boso,[1] Davide Rusca,[1] Cédric Vulliez,[1] Claire Autebert,[1] Misael Caloz,[1] Matthieu Perrenoud,[1] Gaëtan Gras,[1,2] Félix Bussières,[1] Ming-Jun Li,[3] Daniel Nolan,[3] Anthony Martin,[1] and Hugo Zbinden[1]

[1]*Group of Applied Physics, University of Geneva, Chemin de Pinchat 22, 1211 Geneva 4, Switzerland*

[2]*ID Quantique SA, Chemin de la Marbrerie 3, 1227 Carouge, Switzerland*

[3]*Corning Incorporated, Corning, New York 14831, USA*



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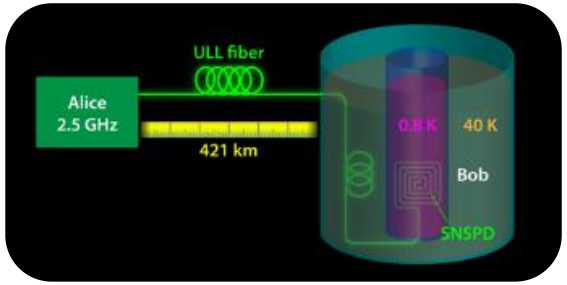


Extra black-body photons filtering

DCR of 0.1 cps
60% efficiency

Long-distance QKD

ID281 SNSPD technology for QKD:

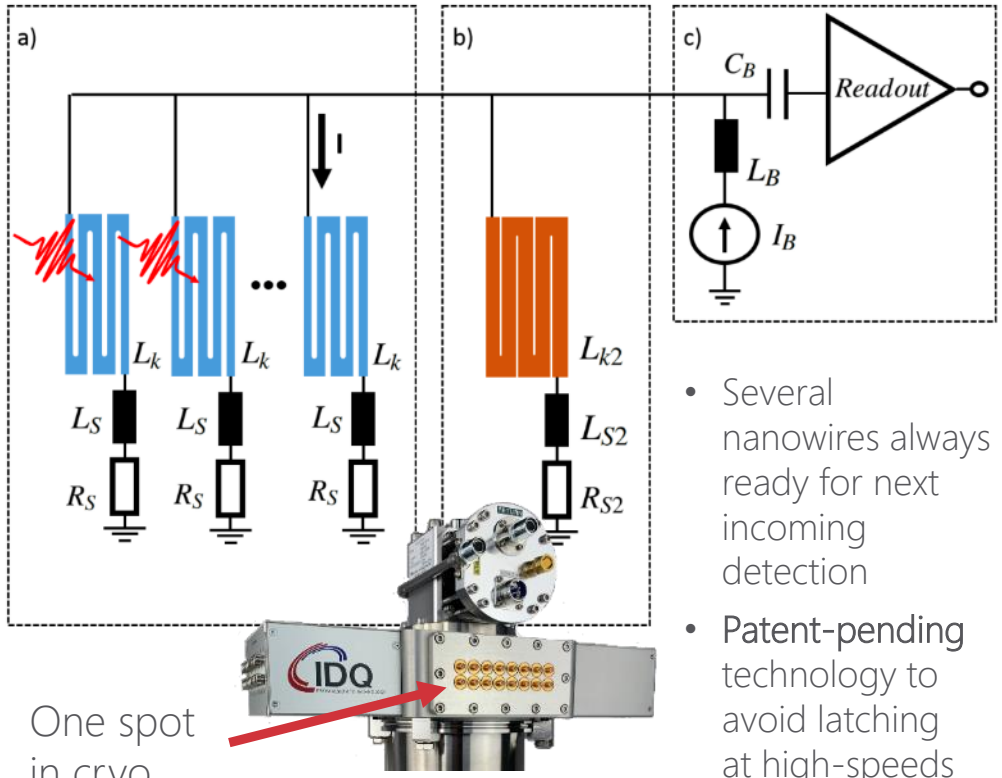
free-running (simple synchronisation) with high-efficiency and low-noise

Ultra-low noise = QKD at record distances

ID281 technology

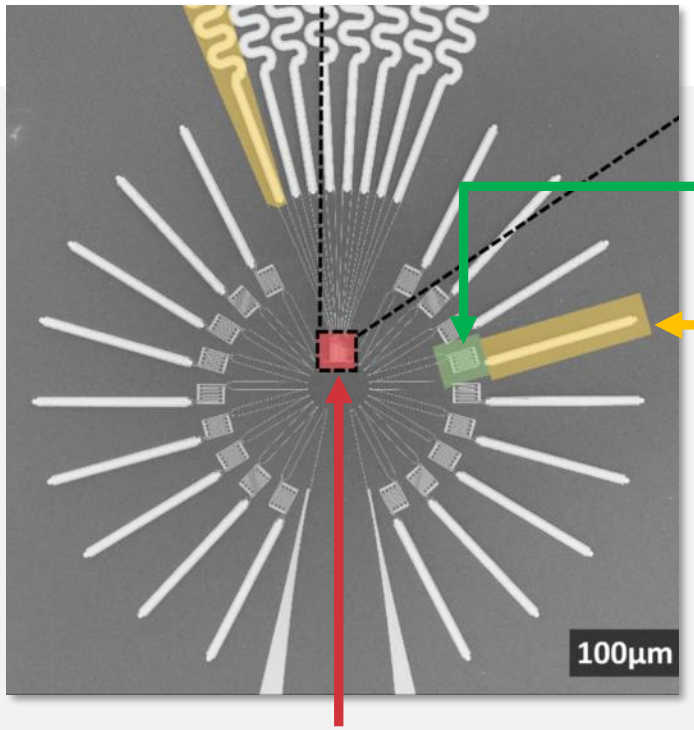
Enabling faster detection rates and photon-number resolution

Connecting several nanowires in parallel for speed and PNR



One spot in cryo

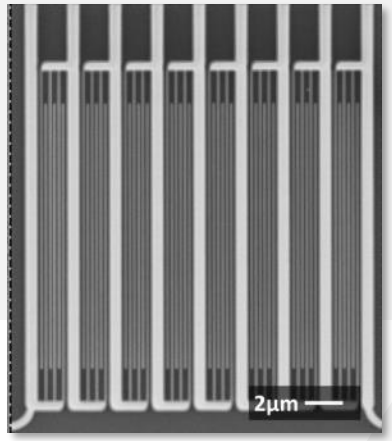
- Several nanowires always ready for next incoming detection
- Patent-pending technology to avoid latching at high-speeds



Unexposed nanowires

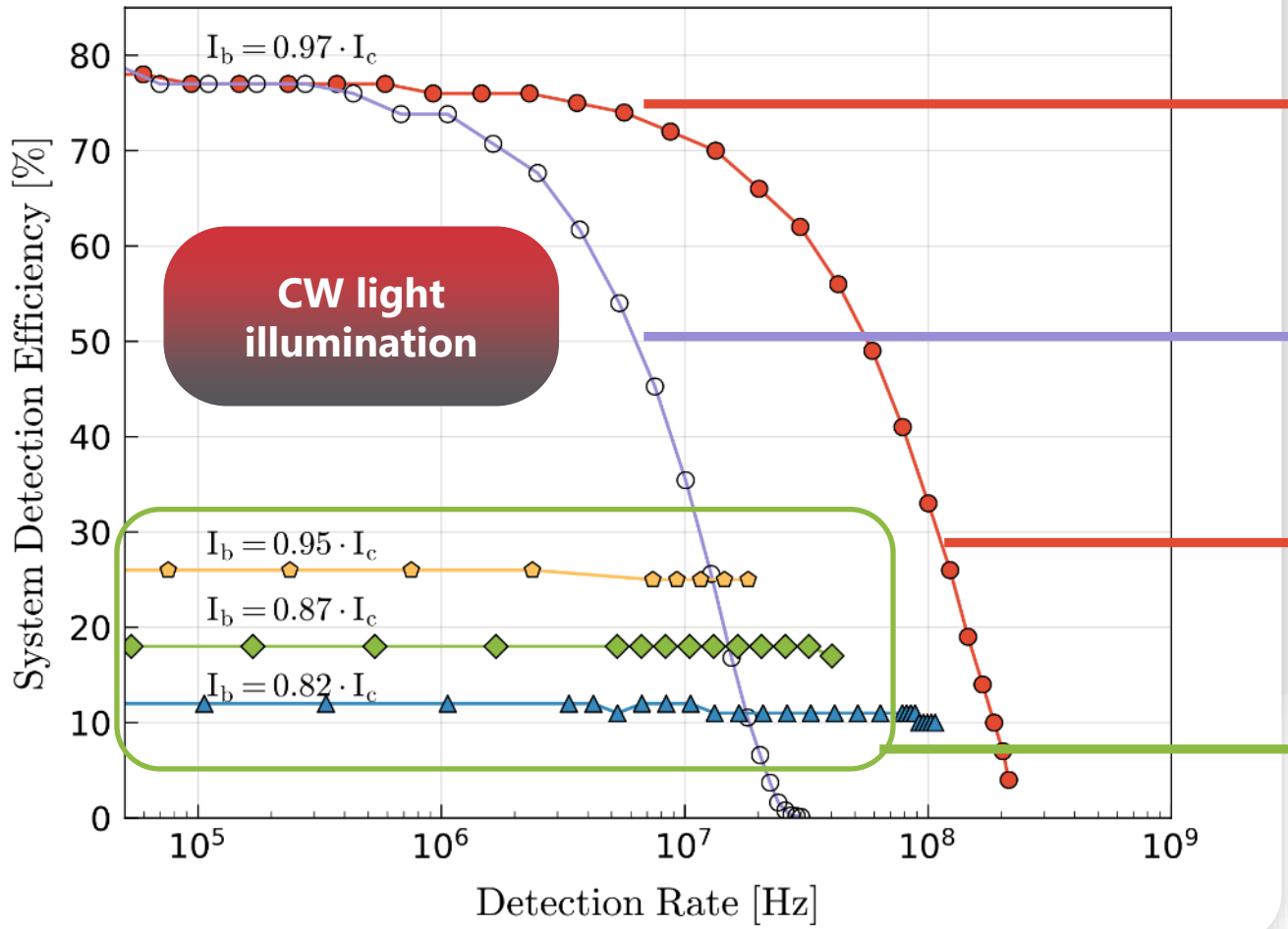
Series resistor

Exposed Nanowires (here 8)



M. Perrenoud et al., SUST 34 024002 (2021)

How well does it speed them up?



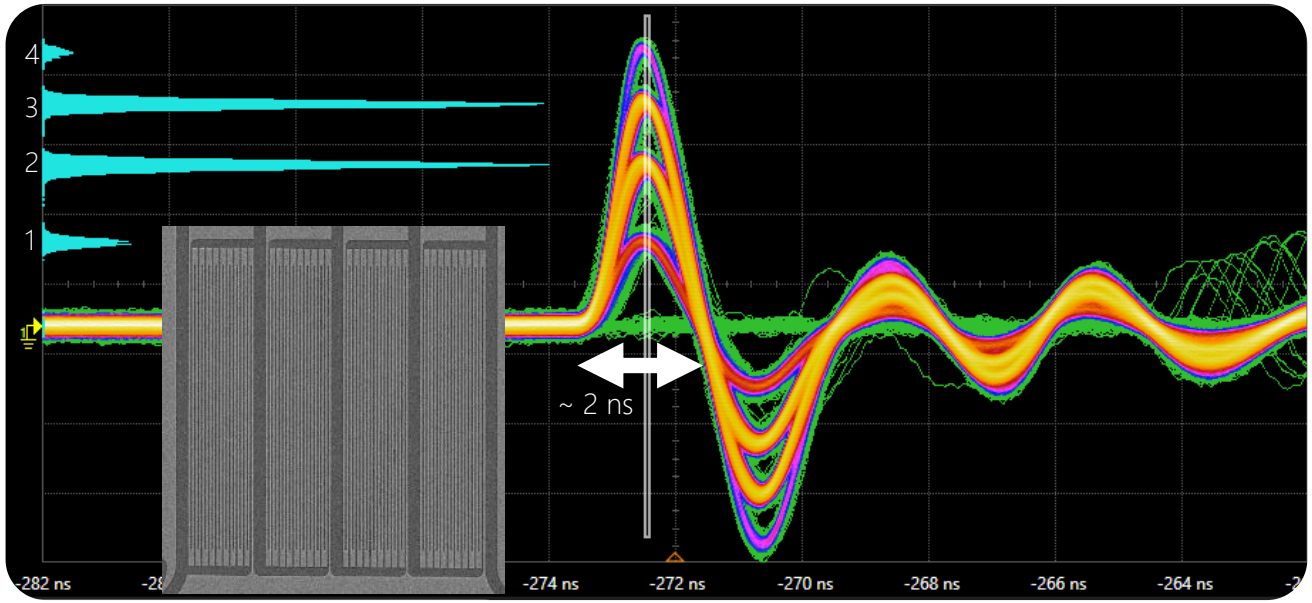
Illuminating with CW light (photons arrive at random times)

- ~80% efficiency at 1550 nm (other wavelengths possible)
- Single nanowire ("normal" SNSPD)
- 6-element parallel SNSPD with the unexposed nanowires (up to 100 MHz and no latching)
- Parallel SNSPDs without the appropriate unexposed nanowires (latching at high count rates and with pulses with several photons)

M. Perrenoud et al., SUST **34** 024002 (2021)

PNR results – 4-pixel device

Inter-arrival time histogram (10 ps incident pulse)



Pristine signal levels with specs like a normal SNSPD

Main features

- No overlap of amplitudes
- No latching

Overall specs

- Efficiency in the 70 to 90% range for one photon
- Jitter = ~30 to 70 ps
- DCR = ~10 to <100 cps

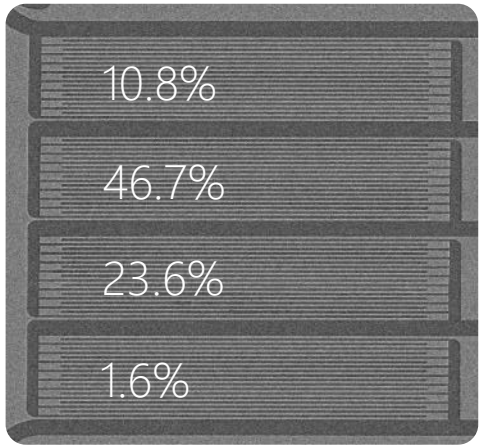
PNR results – 4-pixel device: fidelity analysis

Modelling a 4-pixel device

Number of photon sent

Number of Photon detected

$$\begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{03} & P_{04} & P_{05} & P_{06} \\ 0 & P_{11} & P_{12} & P_{13} & P_{14} & P_{15} & P_{16} \\ 0 & 0 & P_{22} & P_{23} & P_{24} & P_{25} & P_{26} \\ 0 & 0 & 0 & P_{33} & P_{34} & P_{35} & P_{36} \\ 0 & 0 & 0 & 0 & P_{44} & P_{45} & P_{46} \end{bmatrix}$$



Analysis results

- Total efficiency is 82.7%
- P_{11} = 82.7%
- P_{22} = 39.8%
- P_{33} = 9.0%

Questions to answer

- N-photons fidelity?
- Efficiency of each pixel?
- Can input light statistic be reconstructed?

Main results

- Excellent fidelities
- Light statistics reconstructed with repetition
- Towards single-shot reconstruction

Quantum technology enabler!

Advances in Quantum Advantages

NEWS | 23 October 2019

Hello quantum world! Google publishes landmark quantum supremacy claim

The company says that its quantum computer is the first to perform a calculation that would be practically impossible for a classical machine.

Quantum computational advantage using photons

HAN-SEN ZHONG, HUI WANG, YU-HAO DENG, MING-CHENG CHEN, LI-CHAO PENG, YI-HAN LUO, JIAN QIN, DIAN WU, XING DING, [...]
JIAN-WEI PAN +15 authors Authors Info & Affiliations

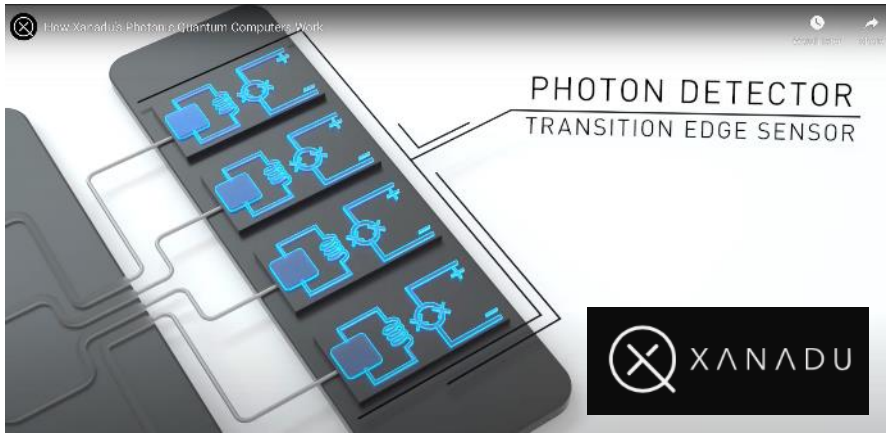
SCIENCE · 18 Dec 2020 · Vol 370, Issue 6523 · pp. 1460-1463 · DOI: 10.1126/science.abe8770

Relied on 60 SNSPDs

Quantum simulations and computing with photons

Growing need for excellent PNR detectors

Squeezed states with PNRs

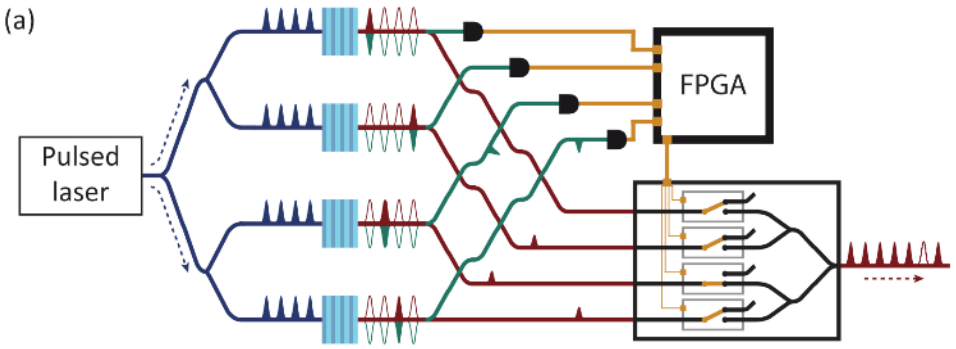


Quantum circuits with many photons on a programmable nanophotonic chip

J. M. Arrazola ✉, V. Bergholm, [...]Y. Zhang

Nature **591**, 54–60 (2021) | Cite this article

High-rate sources of single photons



Photonic quantum information processing: A concise review

Cite as: Appl. Phys. Rev. **6**, 041303 (2019); https://doi.org/10.1063/1.5115814
Submitted: 20 June 2019 . Accepted: 16 September 2019 . Published Online: 14 October 2019

Where we're going

Quantum technologies are set to revolutionize the world we live in.

SNSPD technology and product evolution

- Higher efficiency and speed
- Lower noise and better time precision
- Evolving to the next generation of photonic detection capabilities
- Form factor evolution for seamless integration in several platforms

THANK YOU.

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Q & A

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3. Quantum Sensing

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