QUANDELA

Scale-up quantum technologies with solid-state single-photon sources

5th May 2020

About:

The team:

International experts in solid-state physics and quantum optics

New hiring in 2020 > 3

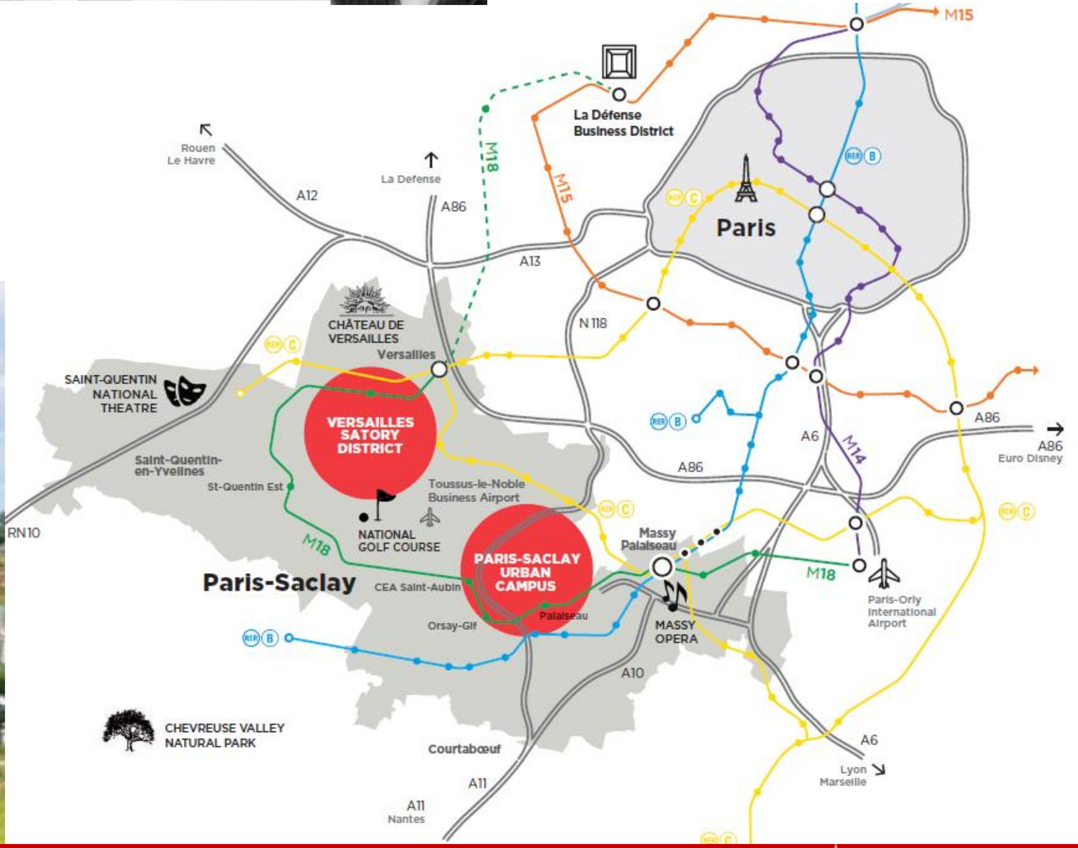
410 PEOPLE

120 RESEARCHERS

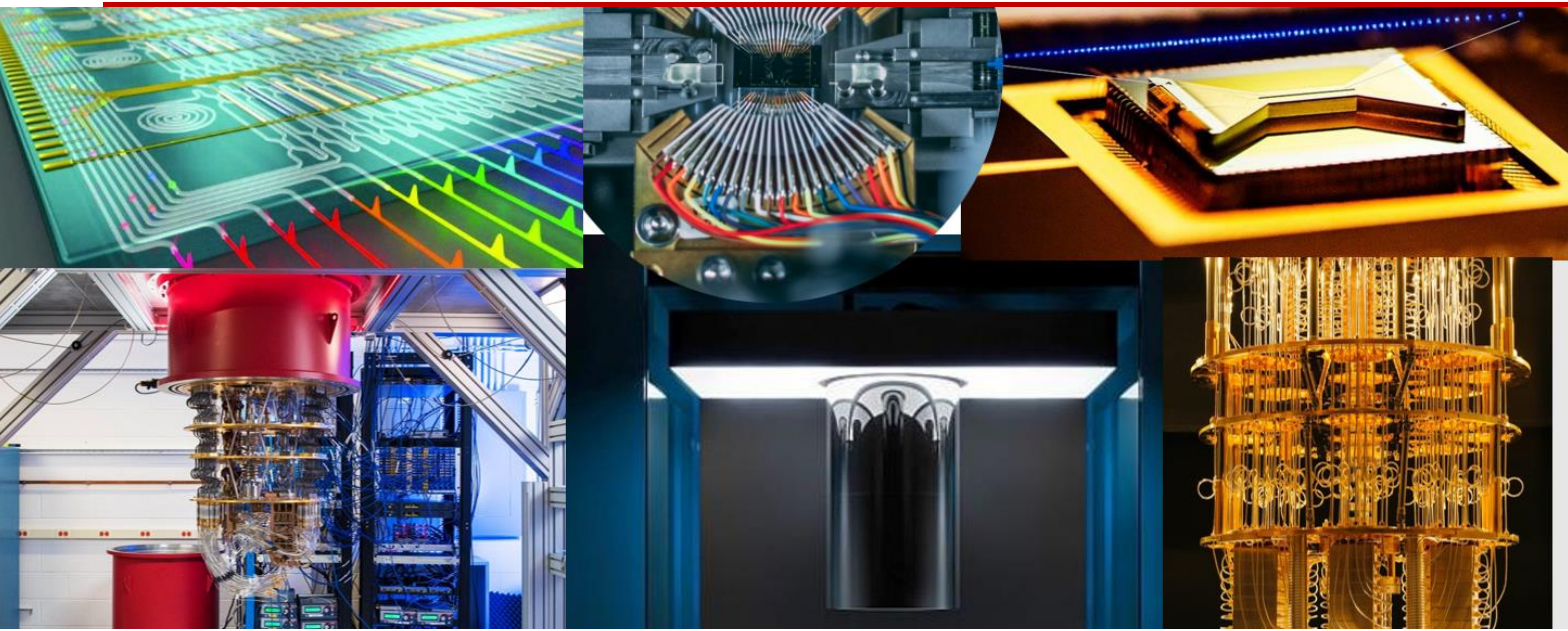
80 ENGINEERS, TECHNICIANS AND ADMNISTRATIVE STAFF

4 RESEARCH DEPARTMENTS

2.900 m^2 clean-room



Quantum computer: the space race of the century

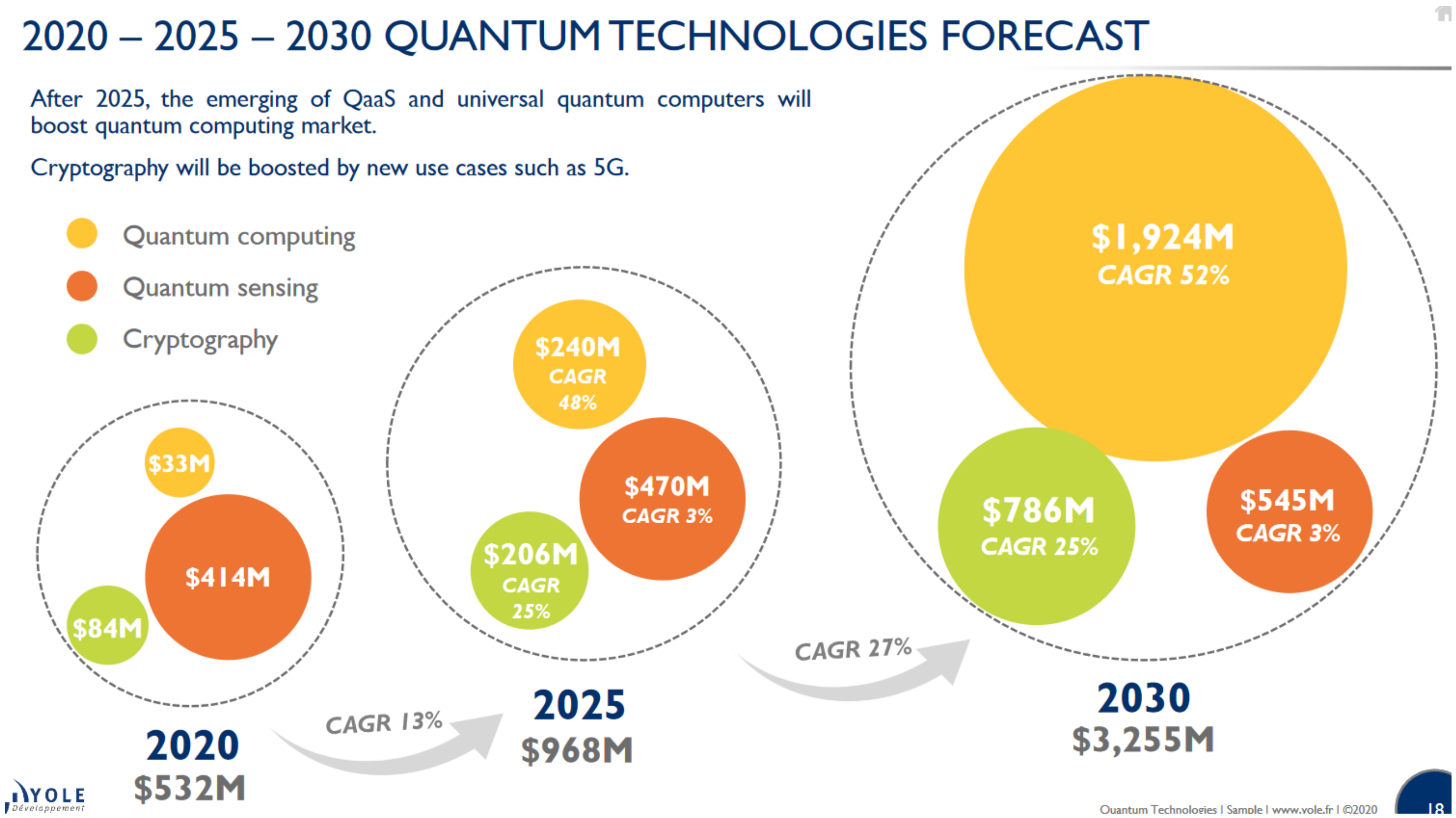


Scientific, Economical & Political

Publications, patents, national investment plans, press, lobbying…

Quantum Technologies will be a must-have for strategic fields

Not only computing



Photonics is at the heart of this Revolution

Flying Qbits (communications) - Quantum Internet

Manipulation of Qubits at room temperature and no vacuum.
Modular design

Protocol flexibility. Generation of cluster states for universal Q computing

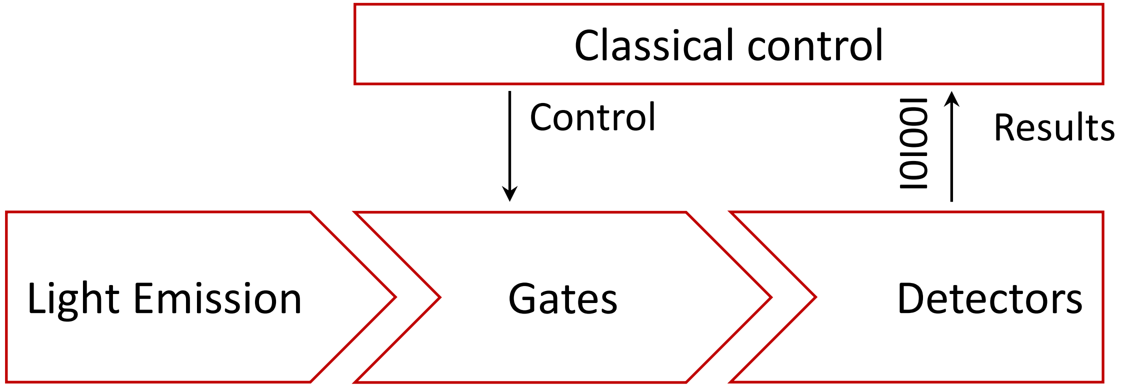
Long coherence time
Support high clock rates

Outline:

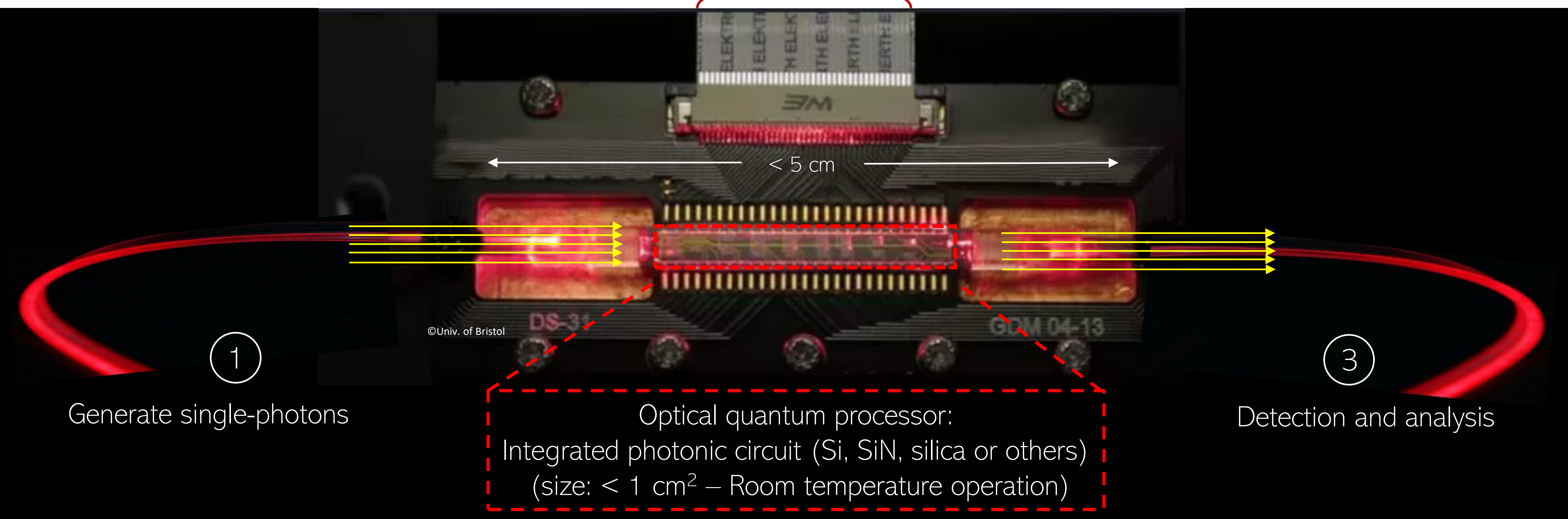
- Single-photon sources for quantum computing
- Quandela's approach
- Implementation and challenges

Optical quantum computing

Sequence of linear optical elements to manipulate a large number of single-photons



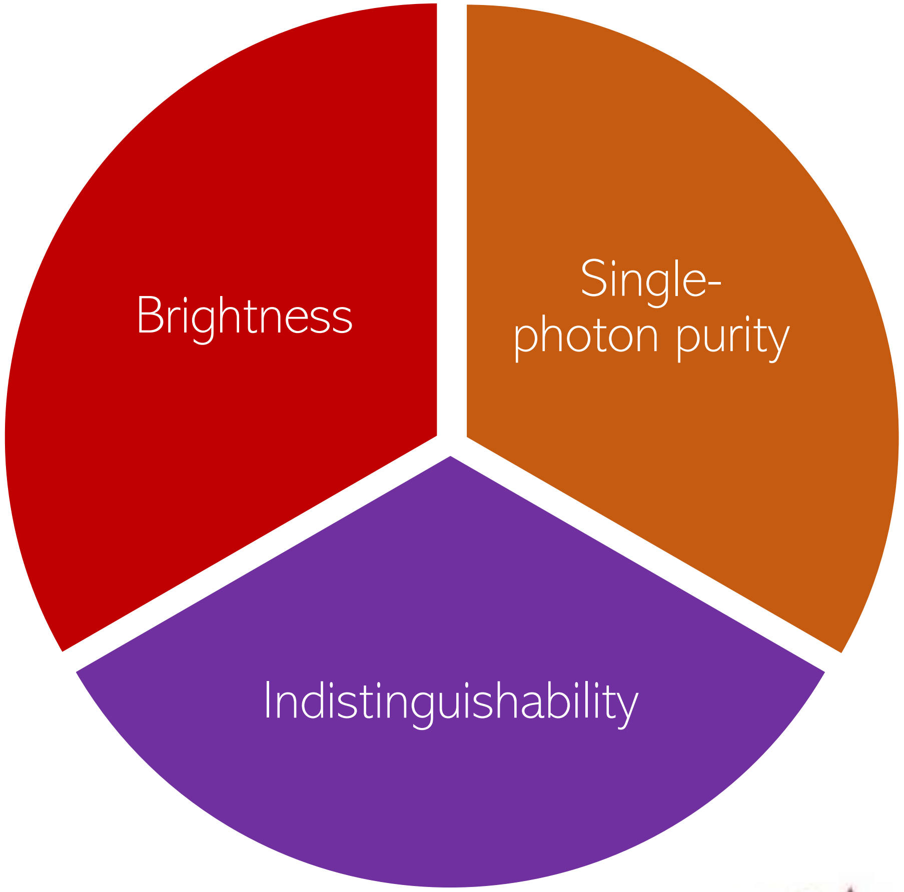
2 Logic gates controlled by a classical PC



Single-photon source performance – figure of merit

Probability of collecting a photon / input laser pulse

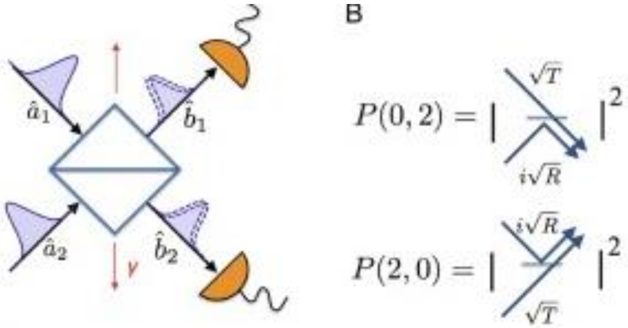
Computation speed - complexity



Probability of having only ONE photon / optical mode

Fidelity of logic gates (errors)

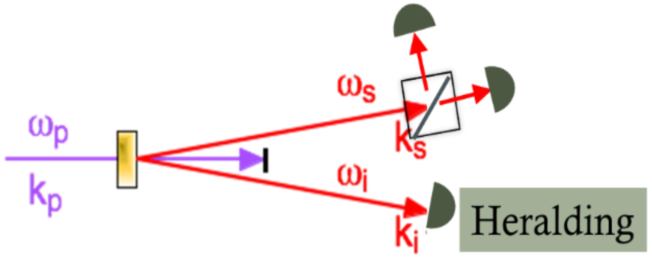
Probability that all photons are identical in every degree of freedom
(required for photon interference)
- Hong-Ou-Mandel -



Efficient emission of Quantum Light is a challenge itself

Laser based – approximated sources

- Attenuated lasers: single-photons
- Lasers + non-linear medium (SPDC – four-wave mixing): indistinguishable and entangled photons



Probabilistic – emission based on Poissonian stats.

require heralding (additional components)

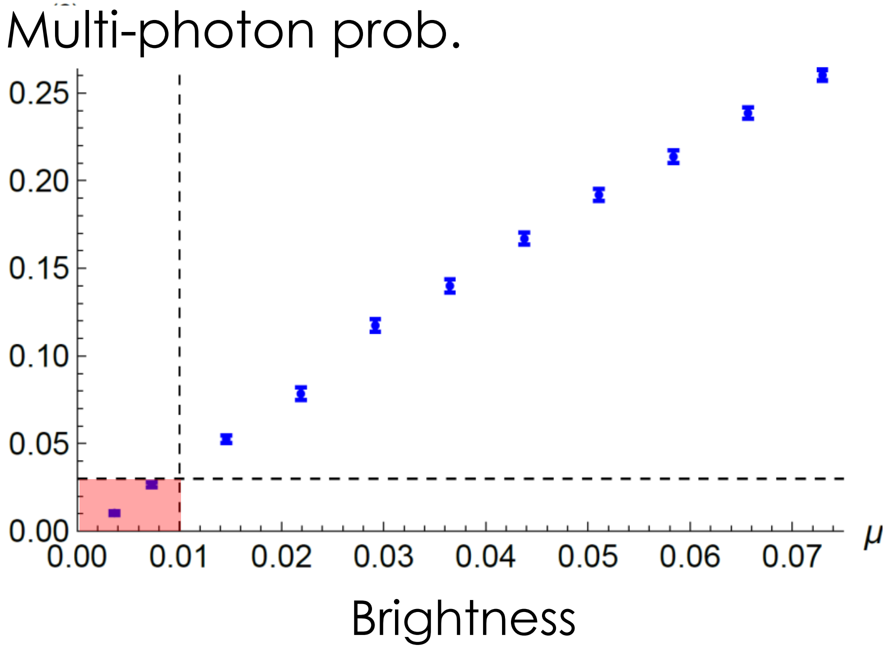
$$|\psi\rangle = \sqrt{1 - |\lambda|^2} \sum_n \lambda^n |n_s, n_i\rangle$$

Brightness proportional to multi-photon emission

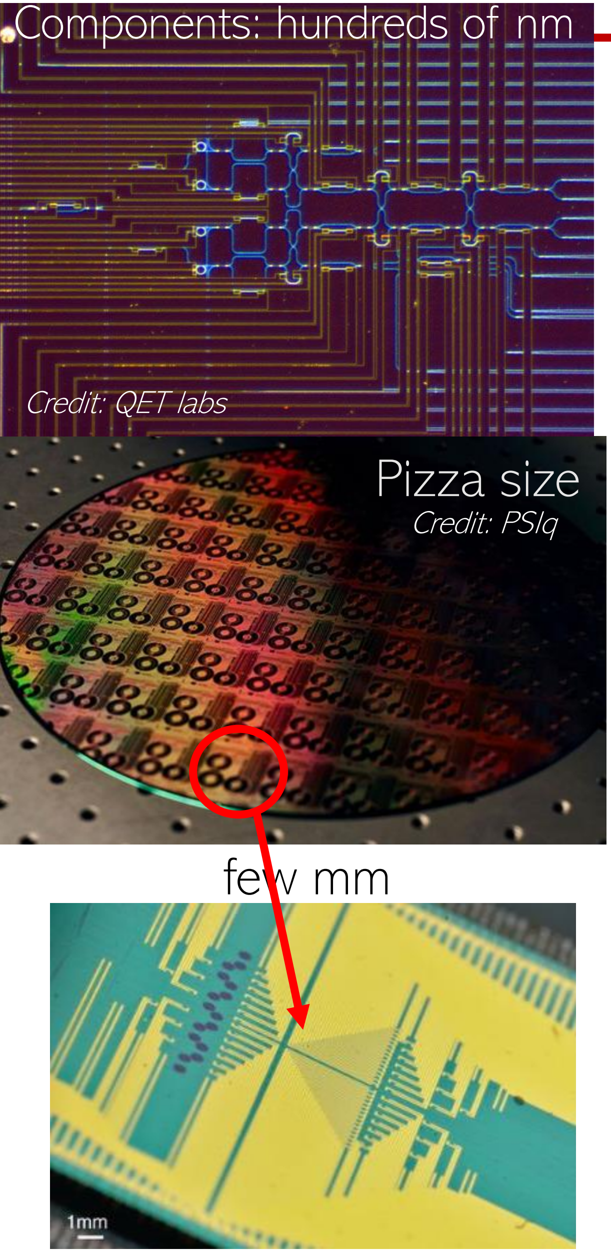
$$(|\lambda| \ll 1) \qquad |\psi\rangle \approx \frac{\lambda}{|\lambda|}|1_s\rangle + \frac{\lambda^2}{|\lambda|}|2_s\rangle \qquad B = |\lambda|^2$$

$$g^{(2)}(0) \approx \frac{2P_s(2)}{P_s(1)^2} = 2|\lambda|^2 \ll 1 \text{ if } \qquad B = |\lambda|^2 \ll 1$$

Intrinsically limited – brightness Vs SP purity

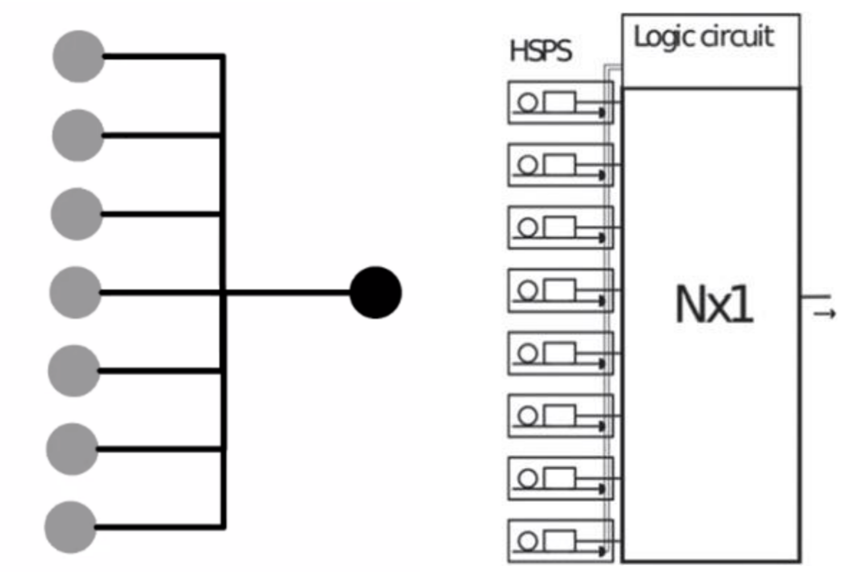


Optical quantum computing



Multiplexing and adaptivity:

"Repeat operations (emission) many times and use classical logic to select successful operations"



Many inefficient heralded sources <u>+ switches, delay lines, more detector & electronics</u>

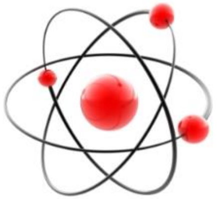
Increasing amount of resources, architecture complexity, PIC space

Base concept in the QC architecture of PsiQuantum

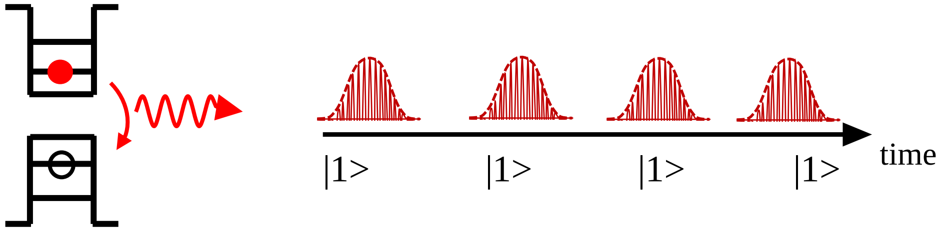
Gimeno-Segovia – phd thesis: Towards practical linear optical quantum computing

Efficient emission of Quantum Light is a challenge itself

Single-emitters



- Natural atoms
- Artificial atoms



Deterministic / push-button emission

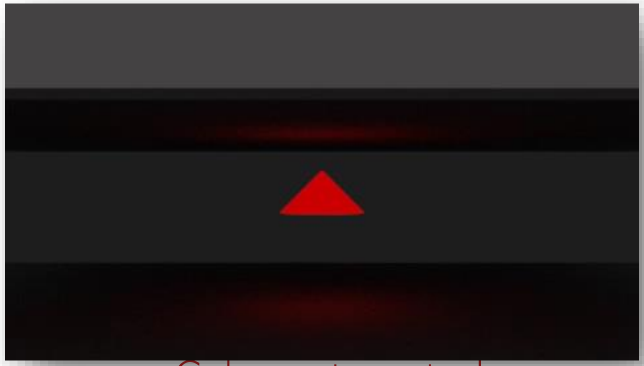
Brightness with no multiphoton emission

$$|\psi\rangle \approx \sqrt{p_0}|0\rangle + \sqrt{p_1}|1\rangle + \sqrt{p_2}|2\rangle, \quad (p_0 + p_1 + p_2 = 1)$$

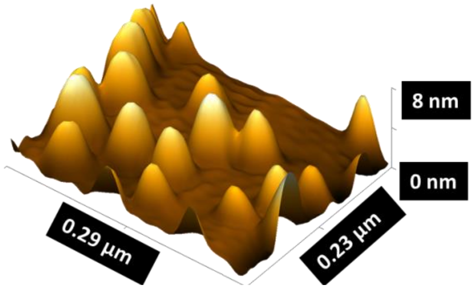
$$B \to 1 \quad \& \quad g^{(2)}(0) = \frac{\sum n\,(n-1)p_n}{[\sum n p_n]^2} \to 0$$

High brightness & high SP purity + indistinguishab.

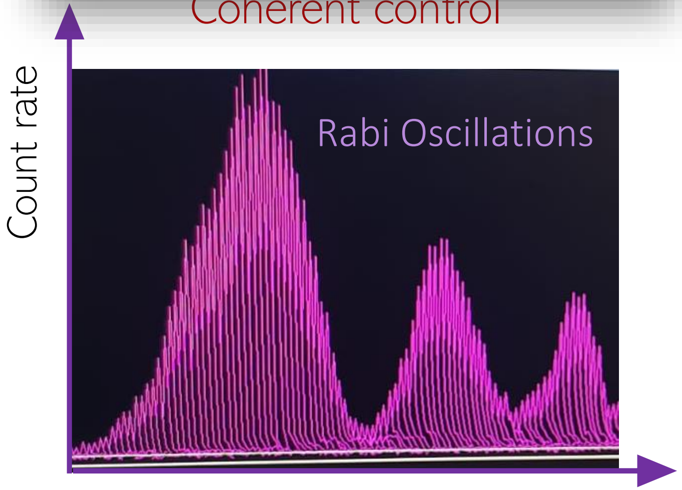
Semiconductor quantum dots = artificial atoms

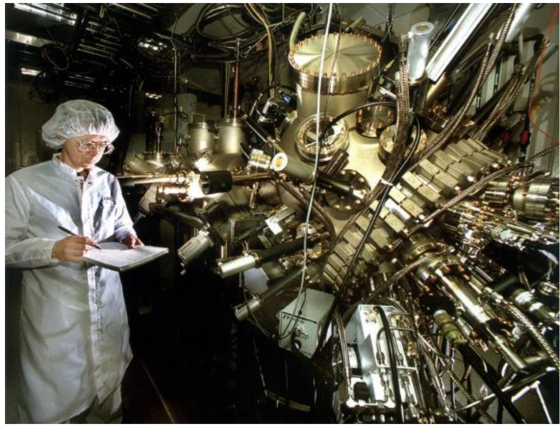


Coherent control



Compatible with III-V semiconductor's industry





White paper can be found at: http://quandela.com/edelight-3

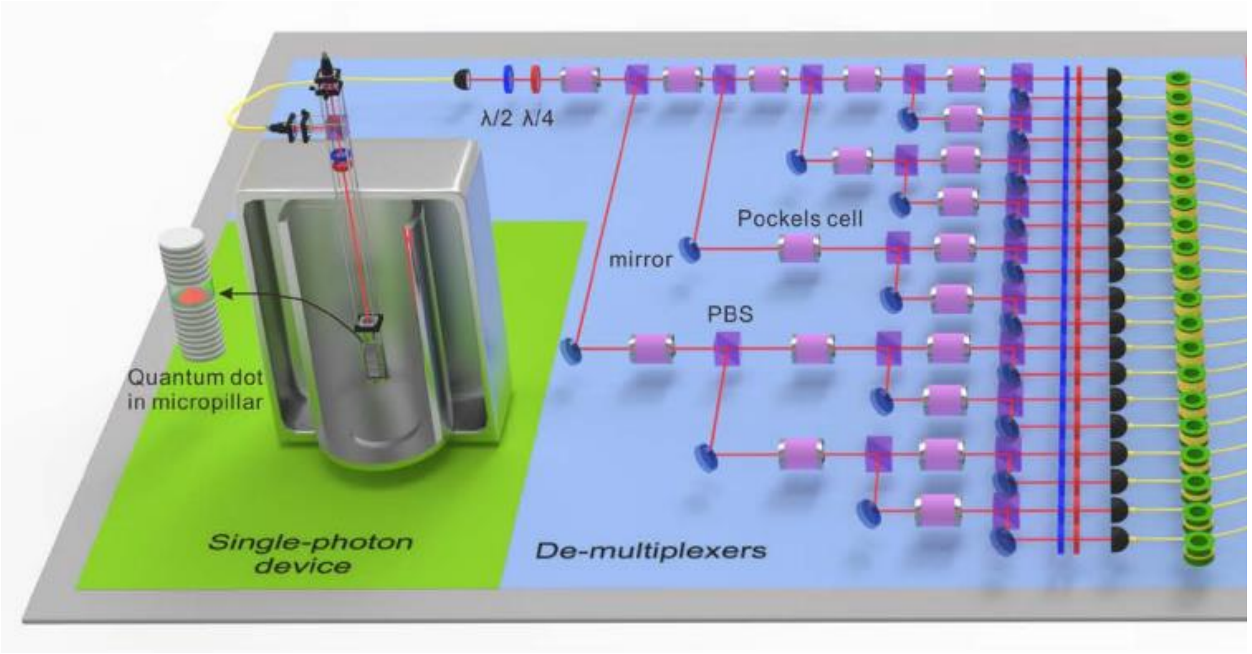
All the photons are then emitted in the same direction, in a gaussian mode.

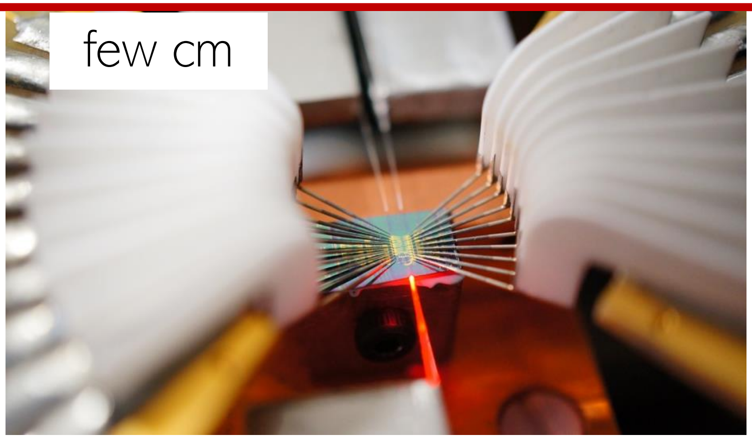
High coupling into a single mode fiber

Optical quantum computing

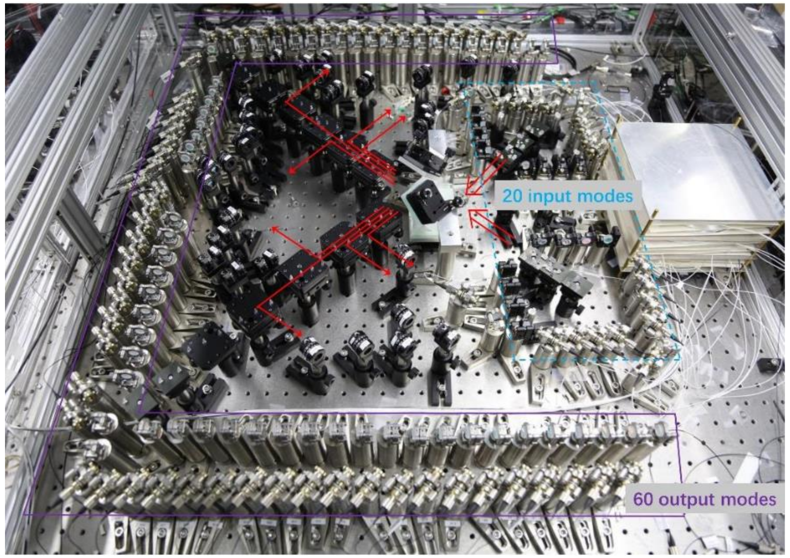
De-multiplexing :

1 highly efficient SP source + routing of temporally separated photons in different spatial modes



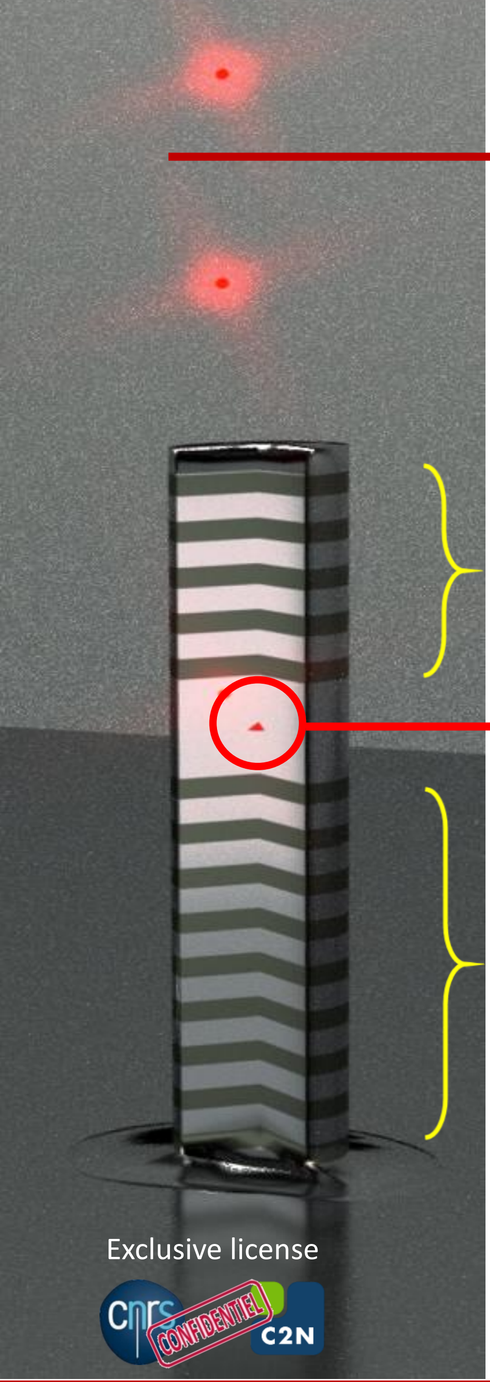


State-of-the-art multi-photon experiment - 20



Credit: Wang et al., Boson sampling with 20 input photons and a 60-mode interferometer in a 10^{14}-Dimensional Hilbert Space, Phys. Rev. Lett (2019)

Control of the photon emission: technological challenge



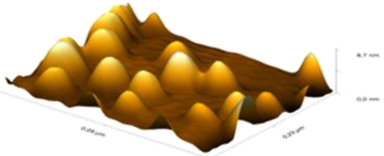
Top Cavity Mirror

Semiconductor Quantum Dot

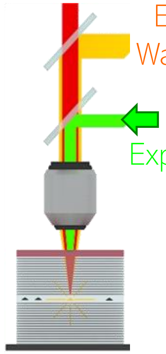
Bottom Cavity Mirror

Mode coupling

Randomness



Laser:
Excitation (850 nm)



10 over 30 devices
Vs
1 over 10.000

S. Unsleber et al arxiv:1512.07453 (2016)

In-situ lithography

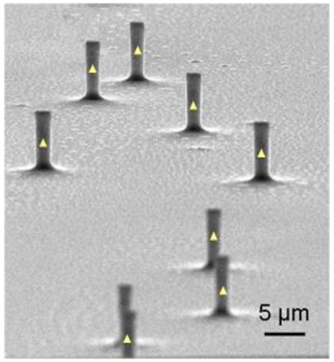
QD – optical mode coupling

$\boldsymbol{\beta} = \mathbf{96\%}$

Dousse et al, PRL (2008)

Out-coupling

Losses



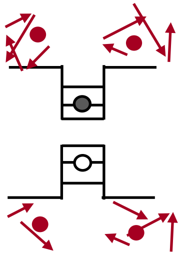
Processing optimization

80 % extraction efficiency

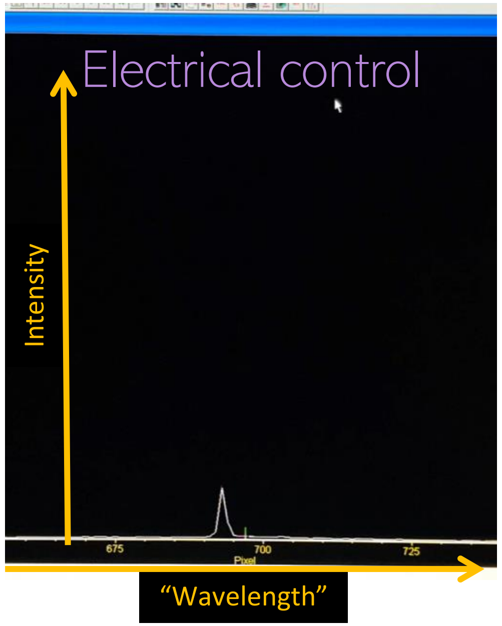
Phys. Rev. Lett. 2012

O. Gazzano et al. Nat.Commun. (2013).

Coherence



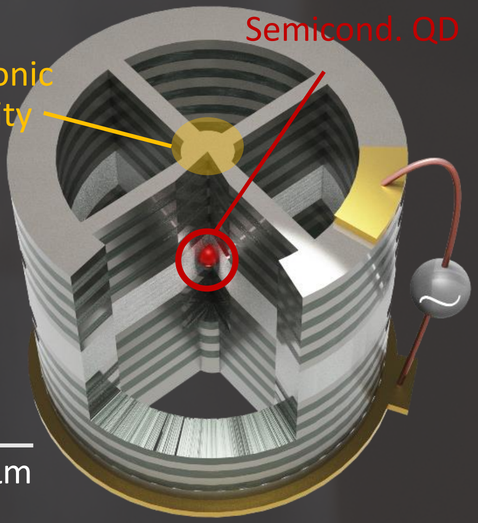
Spin & Charge Noise + Phonons

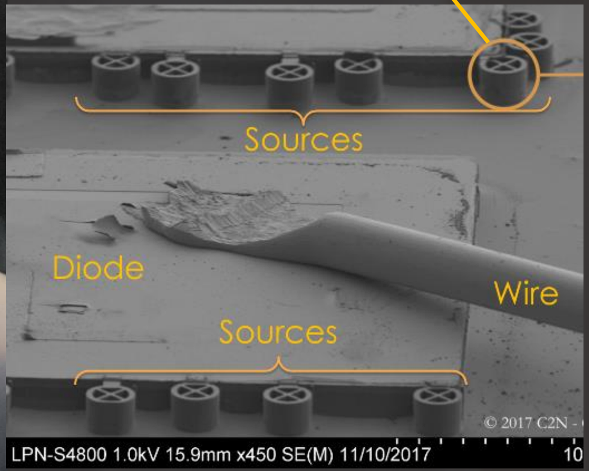


Near-zero dephasing
High indistinguishability

Nowak et.al. Nat. Commun. (2014)
Somaschi et. Al. Nat. Photon. (2016)

Micron size integrated source





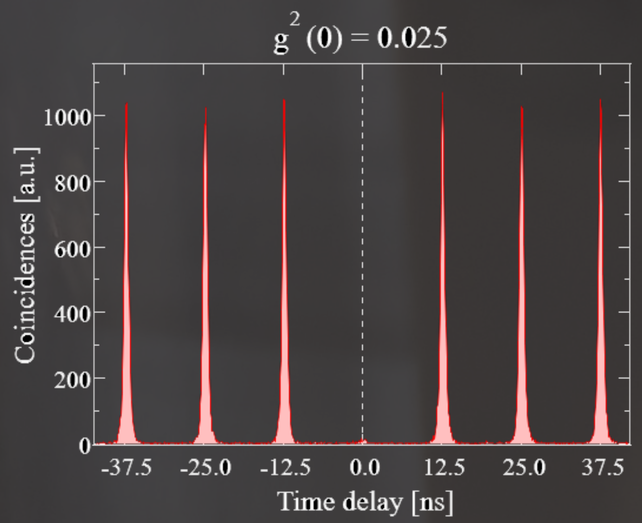
Key Features:

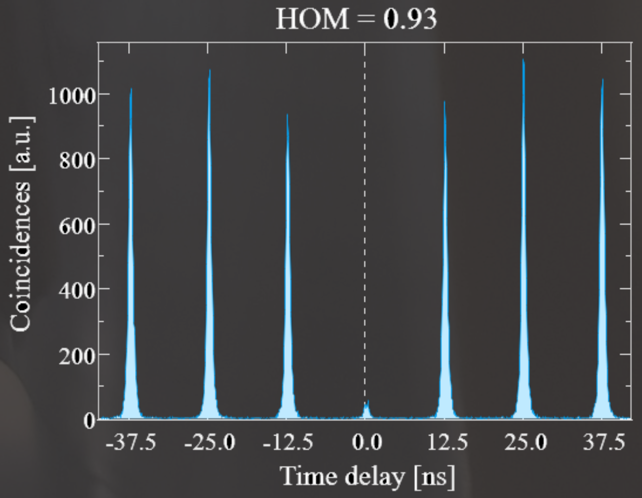
Multi-photon prob.
< 2 %

Indistinguishability
HOM
> 95 %

Brightness
> 20 % (several MHz)

Ollivier et al. doi.org/10.1021/acsphotonics.9b01805. ACS photonics (2020)





	State-of-the-art laser source (Optica Vol.5, issue 5, p. 514-517 – 2018) HOM = 90%	Quandela HOM > 92%	Speed-up
Rate: 1 photon - qubit	1.3 MHz	> 25 MHz	x 20
Rate: 3 photons - qubits	55 Hz	9 kHz	X 160
Rate: 8 photons - qubits	10^{-8} Hz	0.5 mHz	X 50000

Key Features:

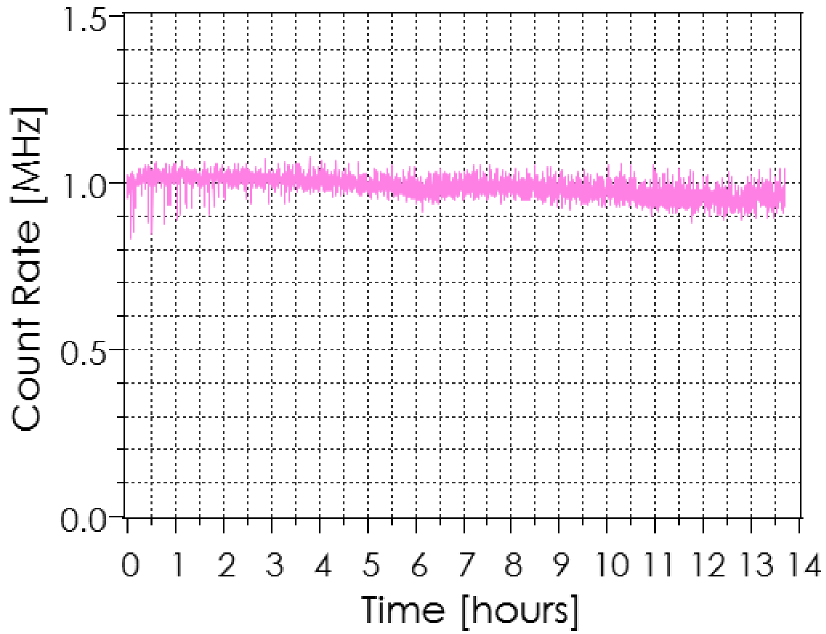
SP purity
> 97 %

Indistinguishability
HOM
> 92 %

Brightness
> 10 % (several MHz)

Compact implementation & efficiency

SP emission stability over several hours



Open facility:

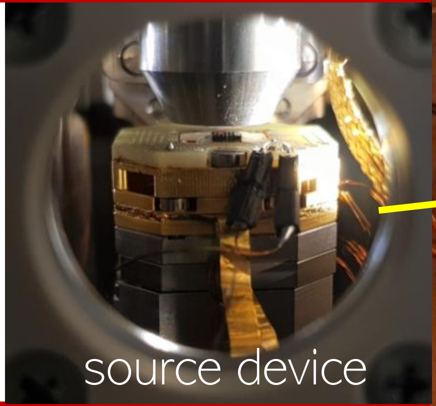
- fully fibered
- full assistance
- possibility for remote experiments

Visit: http://quandela.com/quandelab for more information

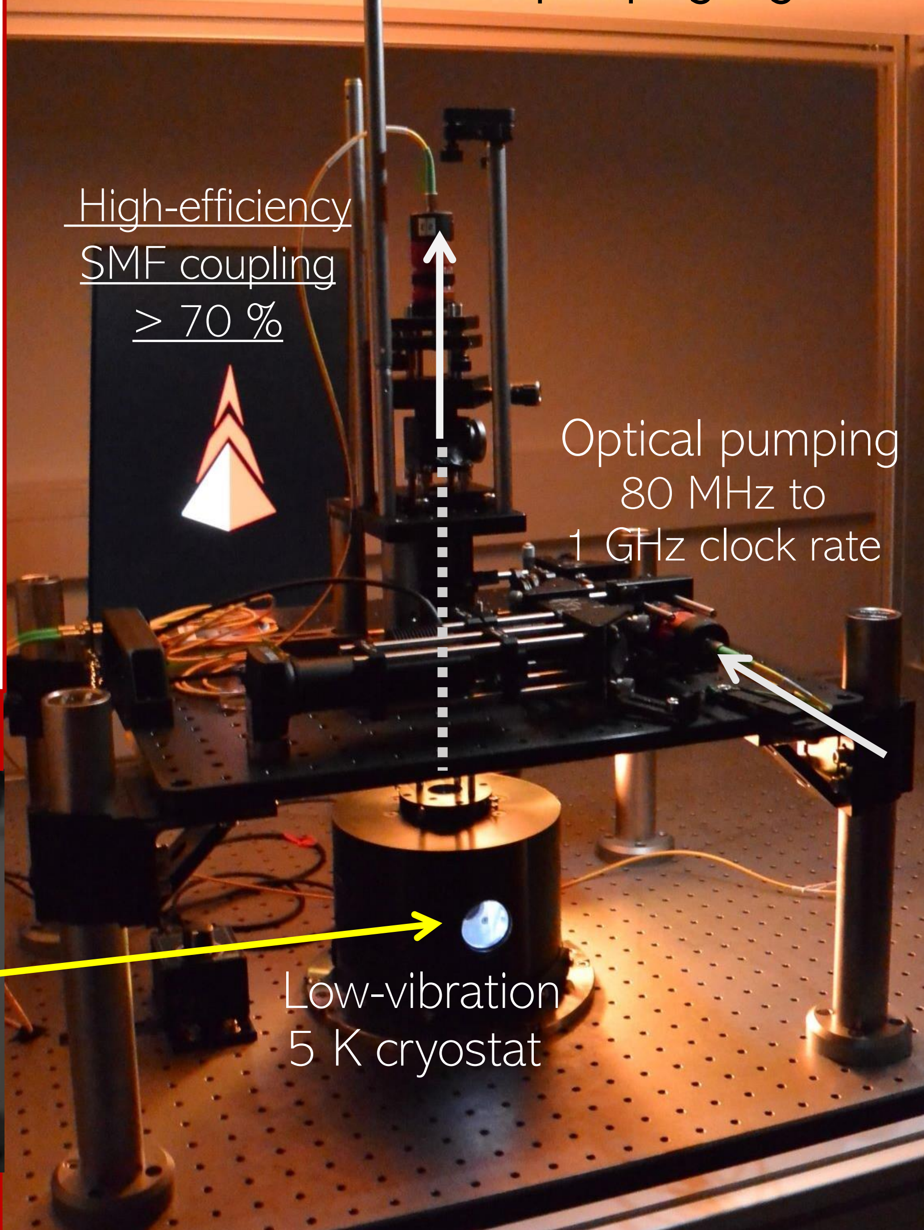
FIBERED OUTPUT, SINGLE-PHOTON COUNT RATE:

- \> 6 MHz at the output fiber @ 80 MHz clock rate
- \> 80 MHz at the output fiber @ 1 GHz clock rate

Efficiency > 10% (20%)



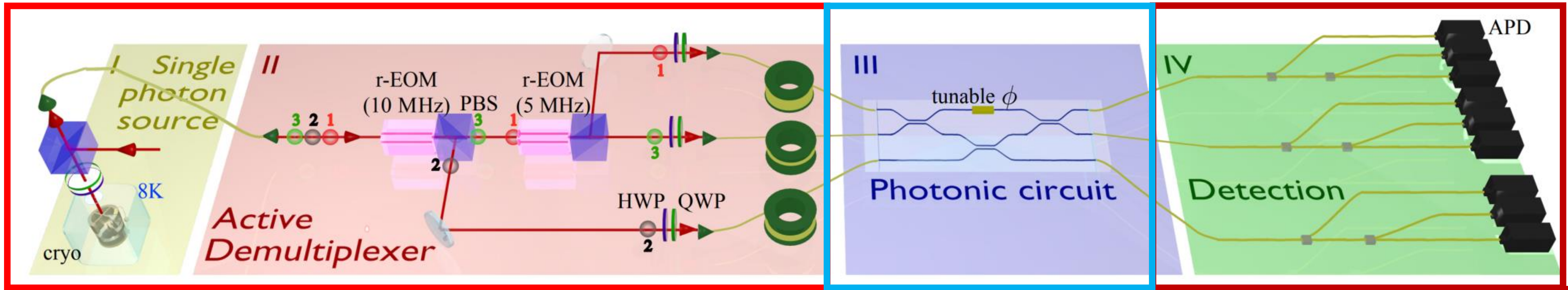
Resonant fluorescence pumping regime

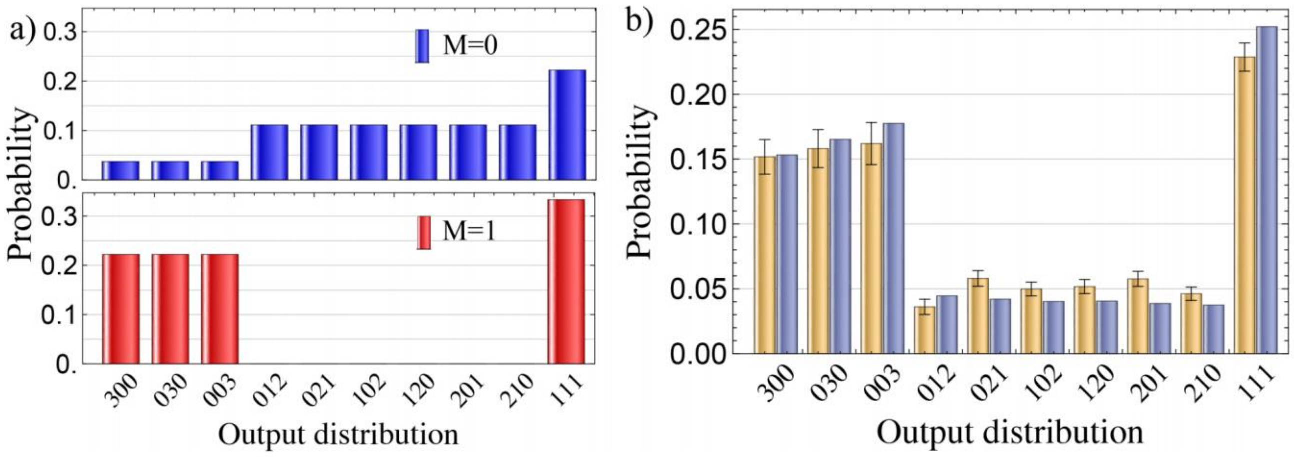


Multi-photons interference on chip

Collaboration:
Prof. P. Senellart – Quandela - Prof. R. Osellame – Prof F. Sciarrino

C Anton et al., vol. 6, 1471, Optica (2019)





3 phot. rate
SPDC 43 Hz
eDelight 3.8 kHz
x 88 brighter

Loss balance + way for improvement

- chip transmission + fiber-array coupling per photon (17% → 60%)
- SP detectors (30% → 90%)
- Brightness and demux transmission (7% & 65% → 50% & 80%)
- Gen. 3-photon rate after chip (19 Hz → 5 MHz)

The open challenges:

1. PERFORMANCE

Increase brightness

Indistinguishability → 99%

Entangled-photons generation

2. USABILITY

Towards stand-alone system and plug-and-play

3. REPRODUCIBILITY + SCALABILITY

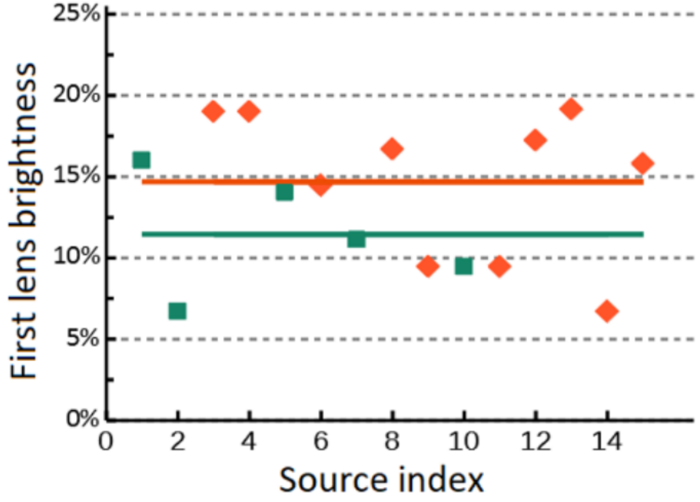
Photon interference from separated devices
Fabrication of several identical devices

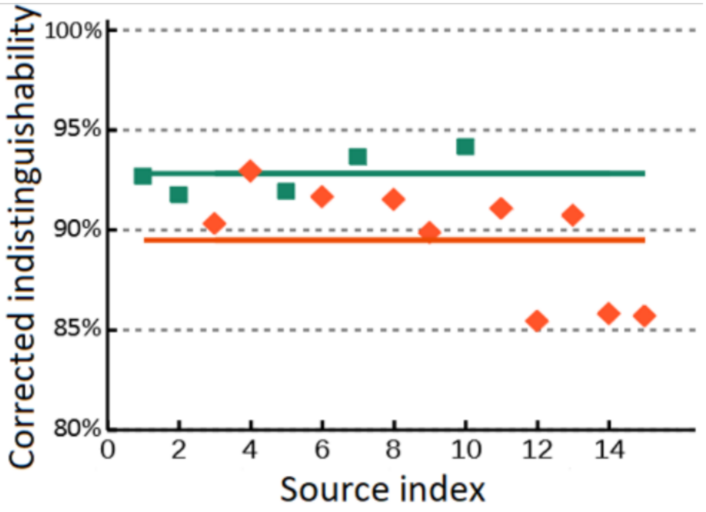
Identical emission wavelength + identical SP temporal profile

Reproducibility and scalability – towards identical sources

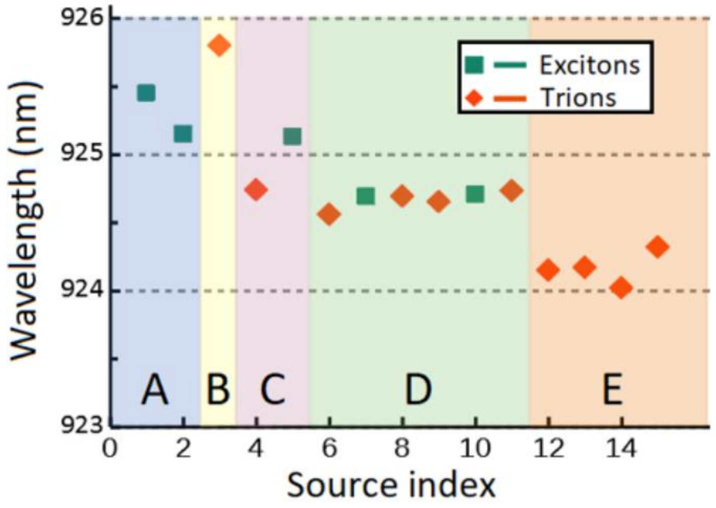
Statistic on 15 sources over 5 different chips

high reproducibility of top-performances

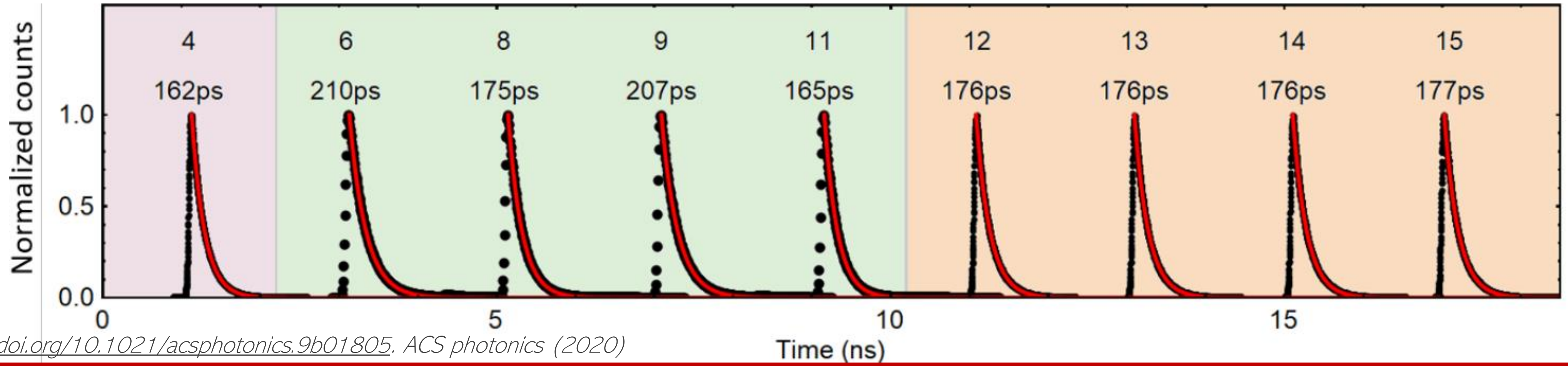




homogeneous emission wavelength



uniform distribution of temporal profiles

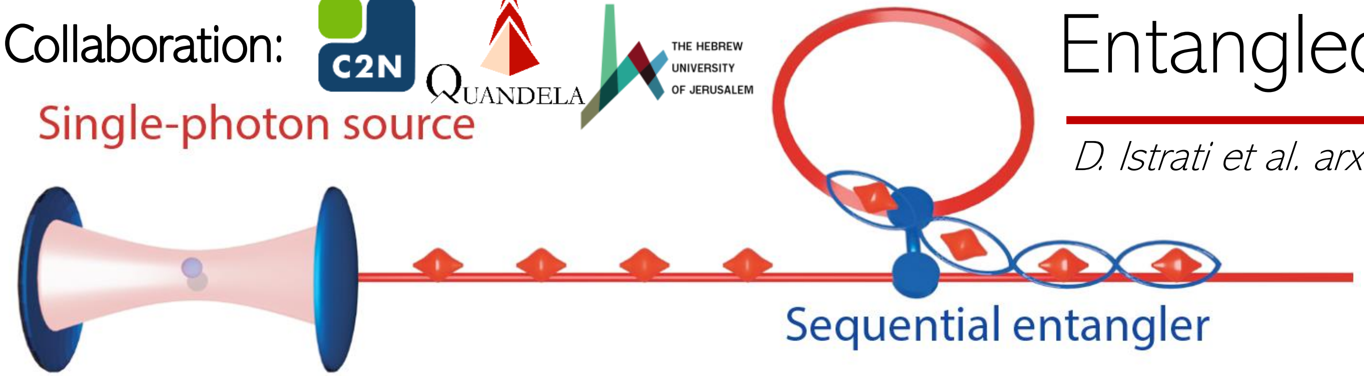


Ollivier et al. doi.org/10.1021/acsphotonics.9b01805. ACS photonics (2020)

Entangled photons cluster state generation

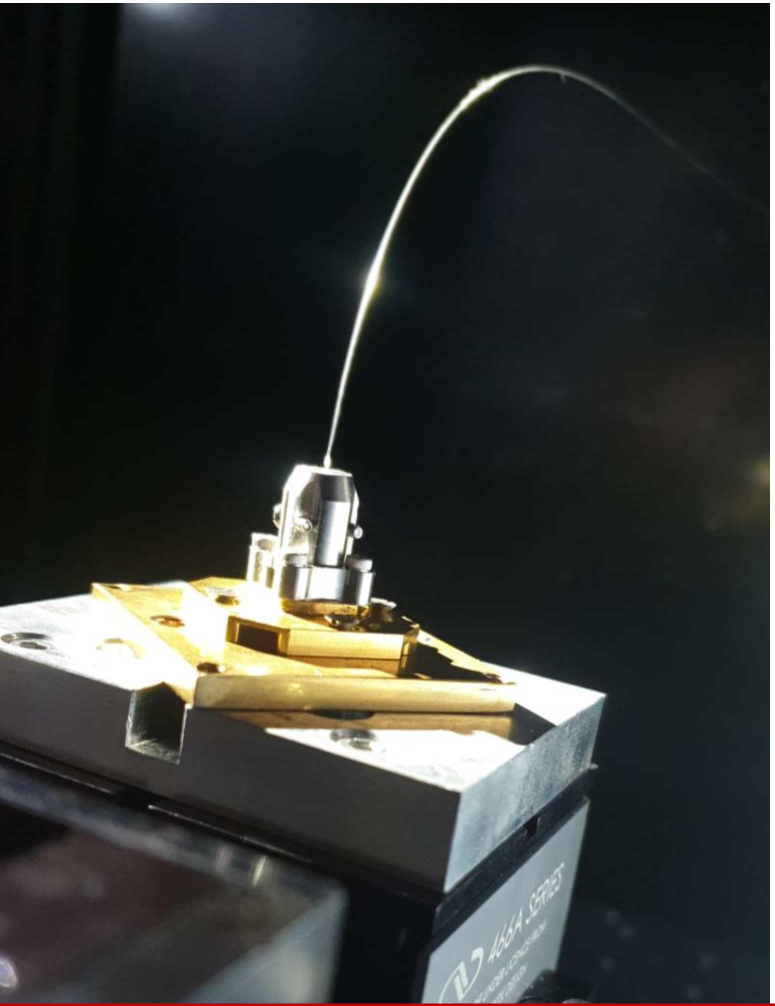
Collaboration:

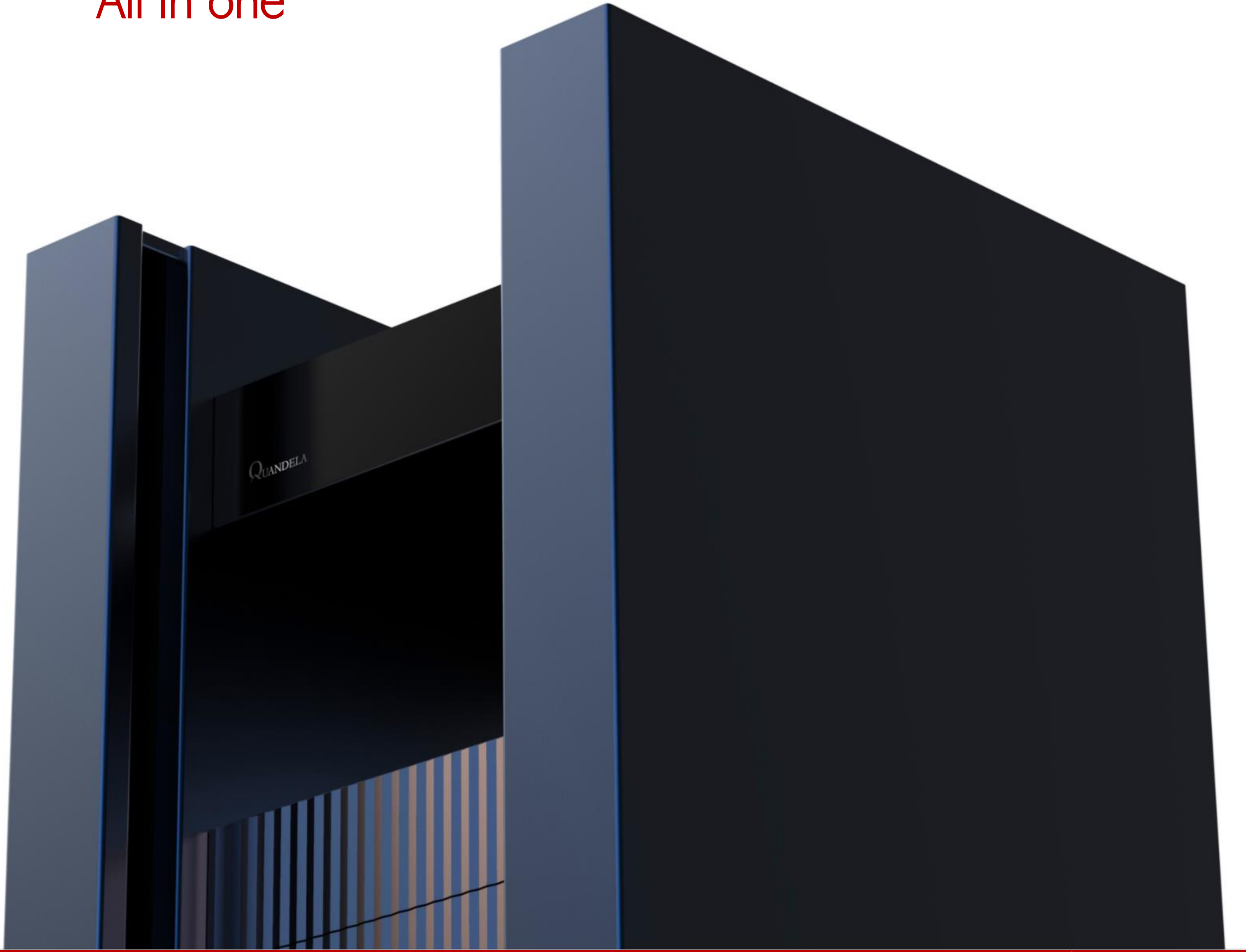
D. Istrati et al. arxiv:1912.04375 (2020)



Next generation of Plug & Play SPS system (available soon)

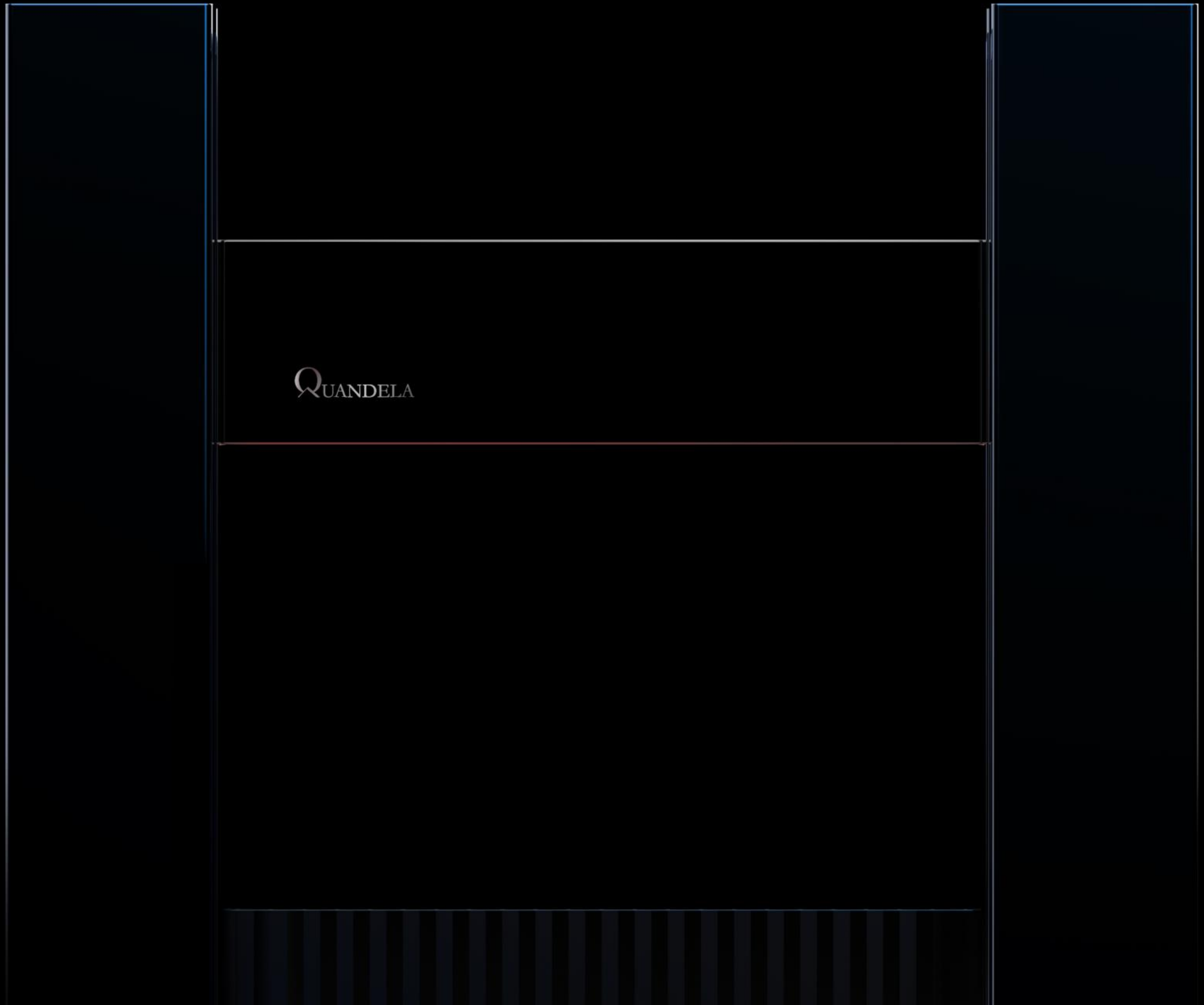
All in one





Next generation of Plug & Play SPS system (available soon)

Thank you



bpifrance i-Lab

DGA

Grant 817021
Grant 861097