QUANDELA

Product catalogue

2021

QUANDELA SAS - 10 Boulevard Thomas Gobert, 91120 Palaiseau (France)
www.quandela.com – contact@quandela.com

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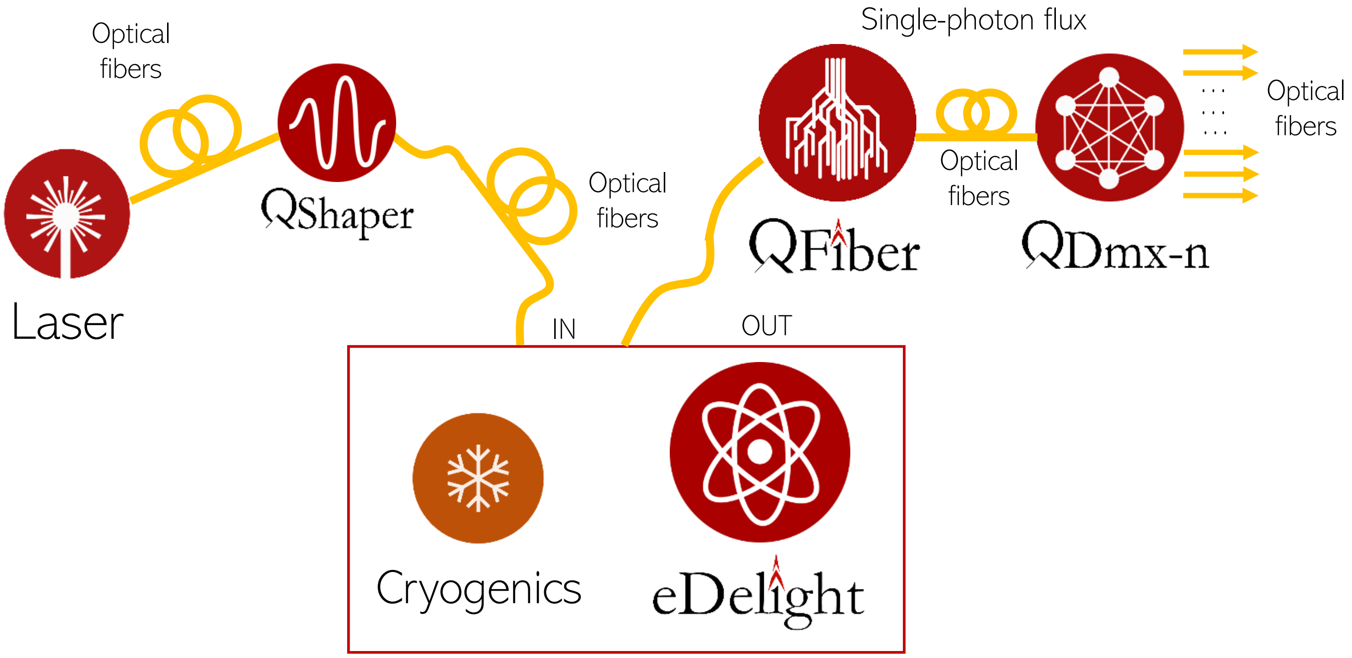
Quandela provides
the opto-electronic modules required for scaling up
optical quantum technologies



PROMETHEUS

All-in-one

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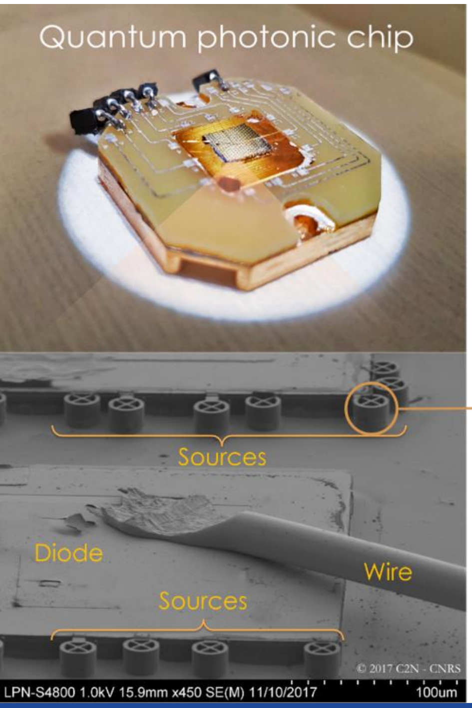
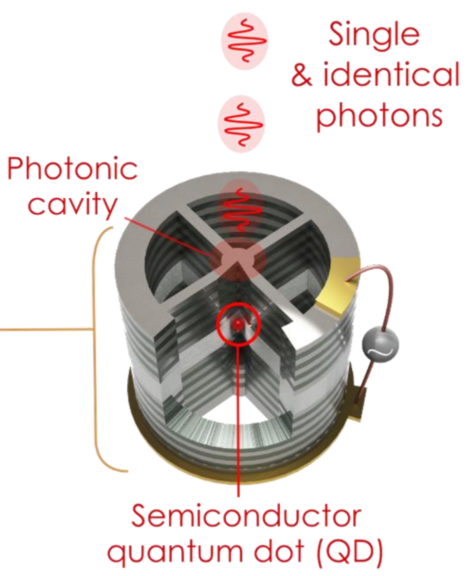
eDelight



Single photon source



Electrically controlled photonic chip containing a set of integrated sources.

<u>Fully deterministic</u>

<u>Reliable</u>

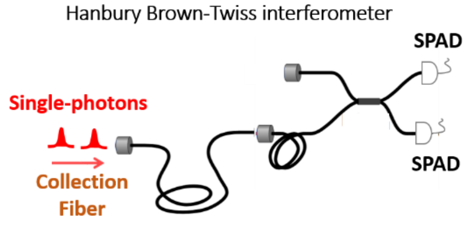
<u>Efficient</u>

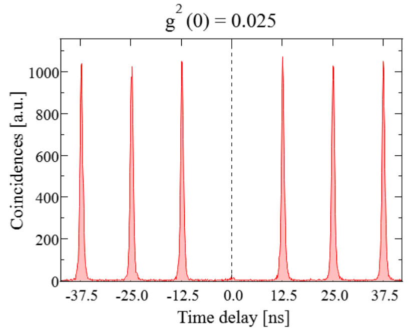
<u>Pure</u>

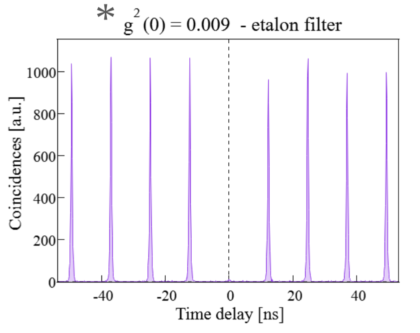
The <u>optical qubit generator</u> efficient and deterministic

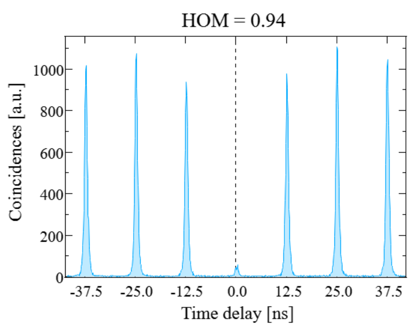
(also available in the pigtailed version)

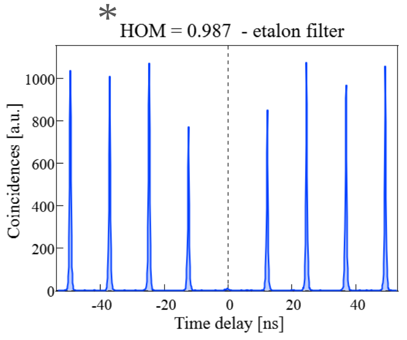
Single-photon purity and indistinguishability

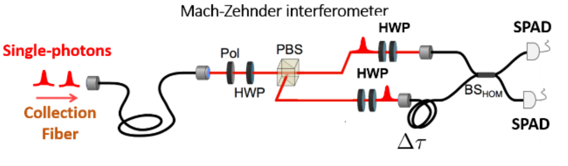












*Measurements performed with the addition of an etalon filter in the collection

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eDelight

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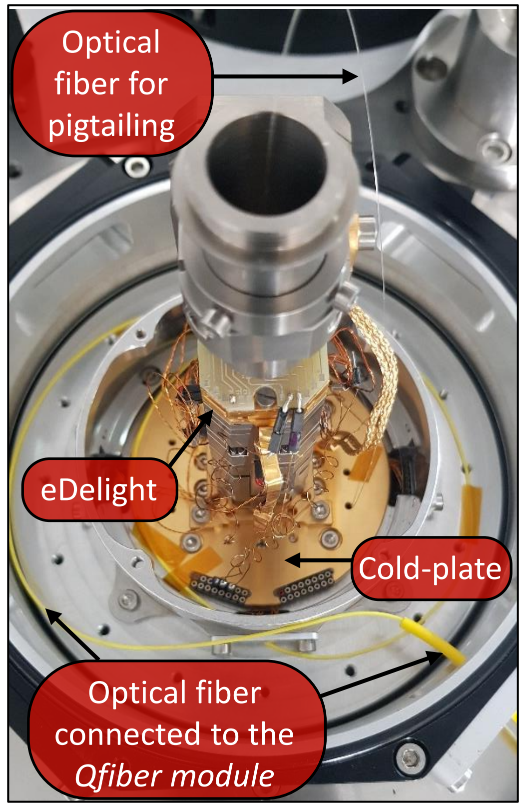
Active-alignment version

The *eDelight* chip is installed in a low-vibration cryogenic system equipped with nanopositioners, for the active alignment of the single-photon sources. Laser excitation and single-photon collection is performed via one single-mode optical fiber placed right on top of the device at 4 Kelvin.

The installation of the optical fiber in the cryogenic system in possession by the customer is performed by Quandela's engineers.



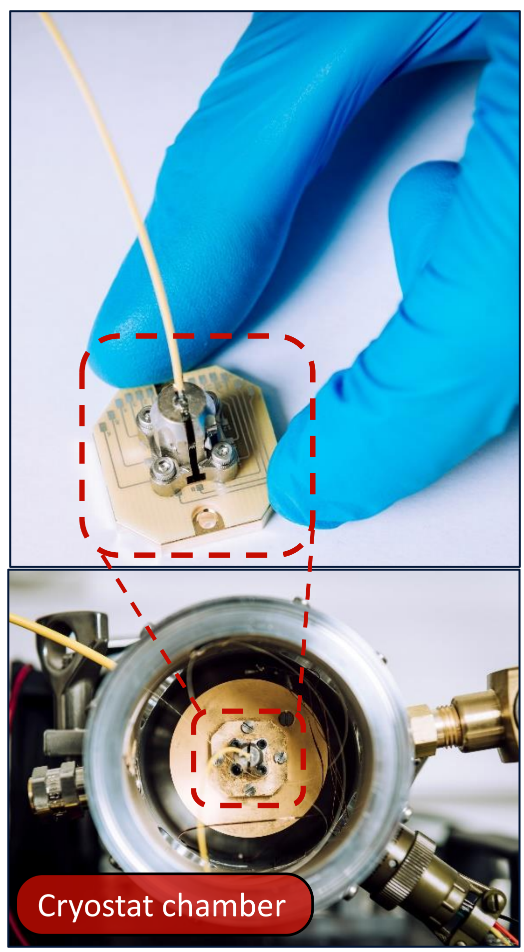
Pigtailed version

A micrometer-size single-photon source of *eDelight* is coupled and pigtailed to a single-mode fiber with high efficiency and long-term stability.

With this technique, the pigtailed *eDelight* chip can be installed in a standard cryogenic system, providing an "<u>alignment free solution</u>": there is no need for nanopositioners, special cryostats, or free-space optical access.

This technology also enables the simultaneous integration of *eDelight* with superconducting nanowire detectors in cryogenic systems.

Consult with our technical support for the compatibility with your existing cryogenic system.



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eDelight QUANDELA

Specifications

Technology	Proprietary fabrication process and design [1], fully deterministic: a unique, selected quantum dot, coupled to the optical cavity mode.
Number of sources per photonic chip usable at choice for the "active alignment" version	> 30 single-photon sources
Single-photon emission wavelength*	925 +/- 5 nm – polarized photons 780 nm (available from 2022)
Excitation laser wavelength	"Resonant" or "near-resonant" regime (detuning -0.5 nm to -0.8 nm)
Electrical control of the emission wavelength	DC external bias (+10 to -10 Volts) – supply bias unit integrated in the module *QFiber*
Brightness	> 30% (single-photon emission probability / laser pulse, at the output of the device)
Single-photon generation rate Maximum excitation clock ≈1 GHz	> 150 MHz (for an excitation clock of 0.5 GHz)
Single-photon purity : $g^{(2)}(0)$	< 5 % [2]
Indistinguishability	> 91 % [3]
Single-photon bandwidth – emitter lifetime	4.5 (+/- 0.5) GHz , < 150 (+/- 50) picoseconds ''Fourier-transform-limited'' emission
Required laser pulse energy[4]	about 10^{-13} J (per excitation pulse)
Required operating temperature	5 – 10 Kelvin
Maximum vibration level / temperature stability	Free-space version: < 50 nm, Pigtailed version: NOT REQUIRED / T. stability: < 50 mK
Physical dimension (photonic chip)	thickness: 5 mm - length: 25 mm - width: 25 mm - weight: < 0.3 kg

*: telecom wavelengths (1550nm – 2200nm) single-photons could be provided in combination with a frequency conversion module (not included).
1: the complete fabrication process is part of the industrial property package
2: calculated by "second order correlation measurement g^2" via Hanbury Brown-Twiss interferometer
3: calculated by ''Hong-Ou-Mandel" interference measurements
4: The average laser power at 0.5 GHz repetition rate is approximately 150 µW

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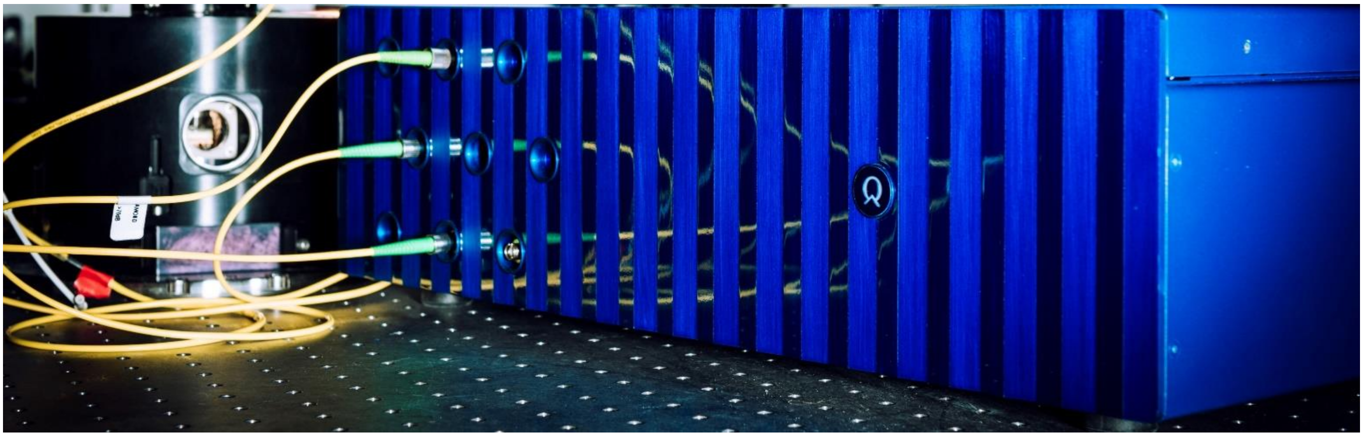
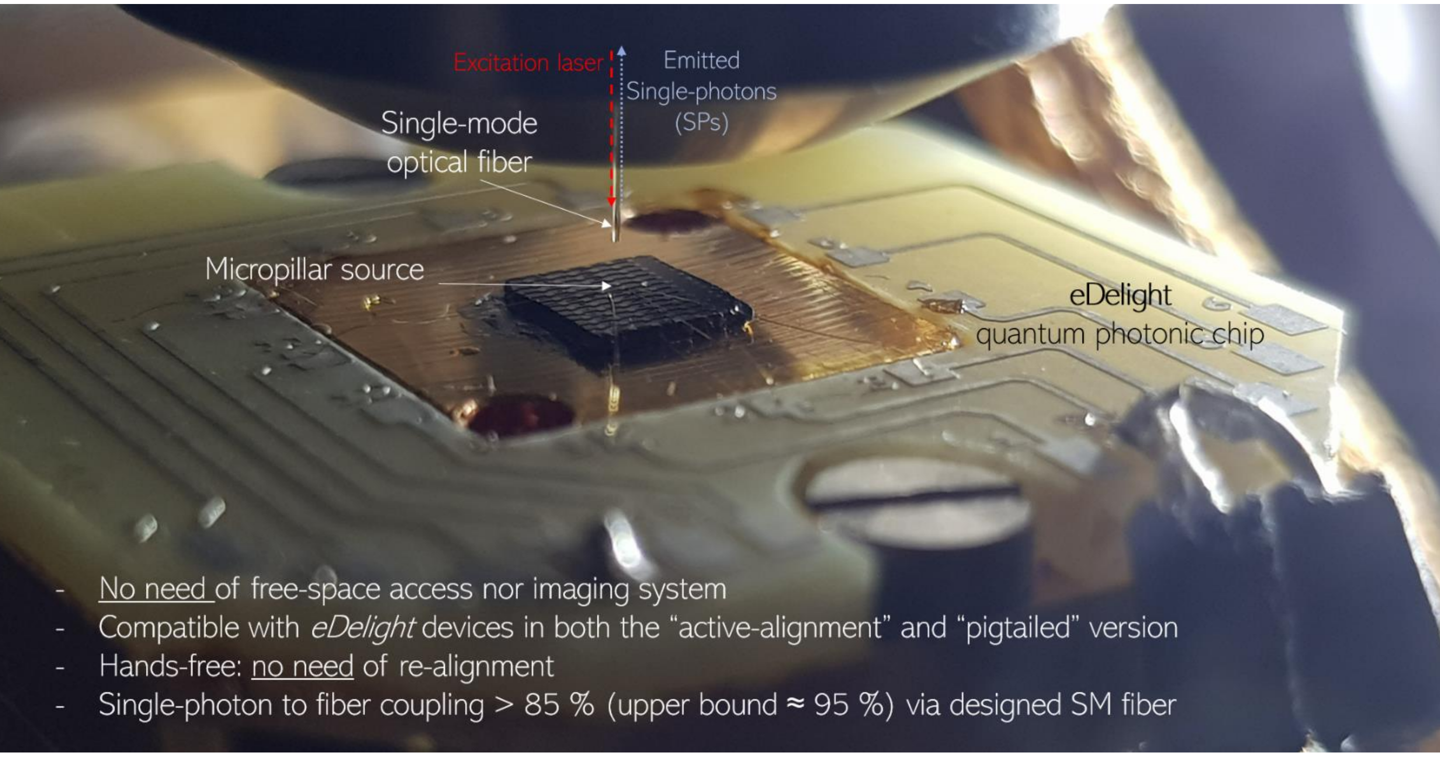
QFiber



A unique module combining electronics and optics for driving *eDelight* devices and interface with other optical platforms (active demultiplexer, photonic circuits etc..)

Compact & Efficient
Qubit Control Unit

Combined with a fibered *eDelight* photonic chip



- No need of free-space access nor imaging system
- Compatible with *eDelight* devices in both the “active-alignment” and “pigtailed” version
- Hands-free: no need of re-alignment
- Single-photon to fiber coupling > 85 % (upper bound ≈ 95 %) via designed SM fiber

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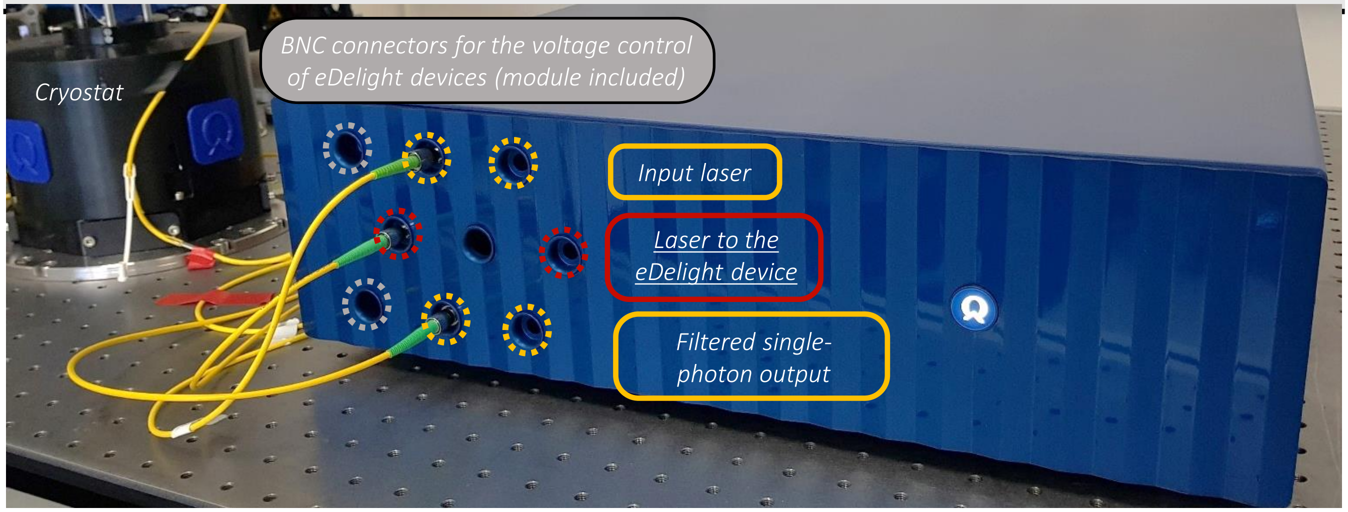
Specifications

Technology	Design by Quandela; pigtailing of the *eDelight* single-photon sources via a single-mode optical fiber.
Electrical control of the *eDelight* device	Output bias: - 10 to + 10 Volts (DC)
Optical control of the *eDelight* device	Custom design for optical excitation via near-resonant regime (detuning > 0.5 nm) or resonant regime
Efficiency (total optical transmission, from the source device to the fiber output)	> 70%
Single-photon to single-mode fiber coupling (active alignment version)	> 90% Maximum Theoretical value ~ 95%
Fibered Brightness (single-photon emission probability / laser pulse, measured at the fiber output)	> 21% (it corresponds to a single-photon rate of 105 MHz – for 0.5GHz laser repetition rate)
Optical (polarization) and mechanical stability (coupling)	Limited signal fluctuation over days
Physical dimensions	Height: 150 mm, width: 490 mm, length: 470 mm – weight: < 8 kg
Electrical connections	100V/120V/230 V, 50 Hz



PLEASE NOTE: the module can include two optical setups and be configured to control either:
- two separate *eDelight* devices at the same time
- one *eDelight* device by choosing in between two different driving regimes (near-resonant or resonant)

Contact us to discuss which configuration is the most adapted to your application.

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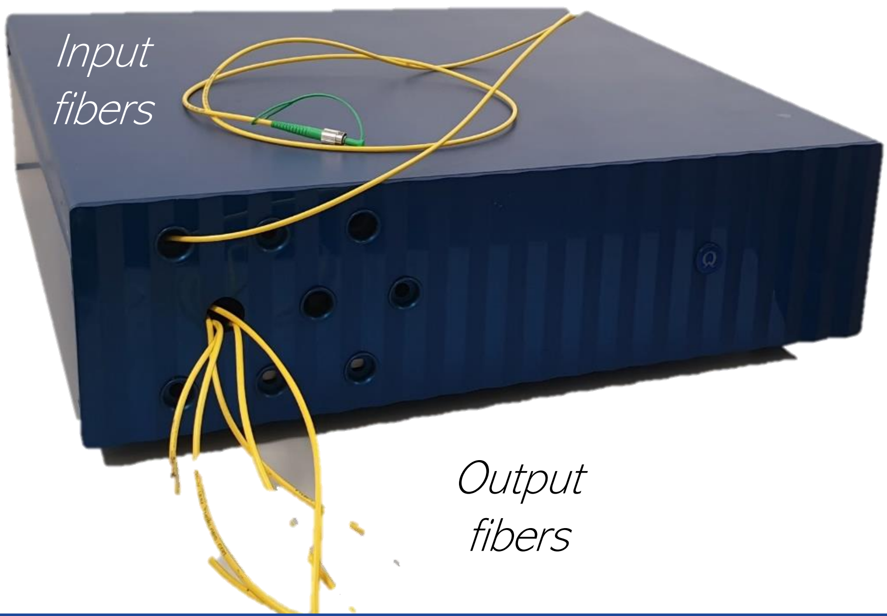
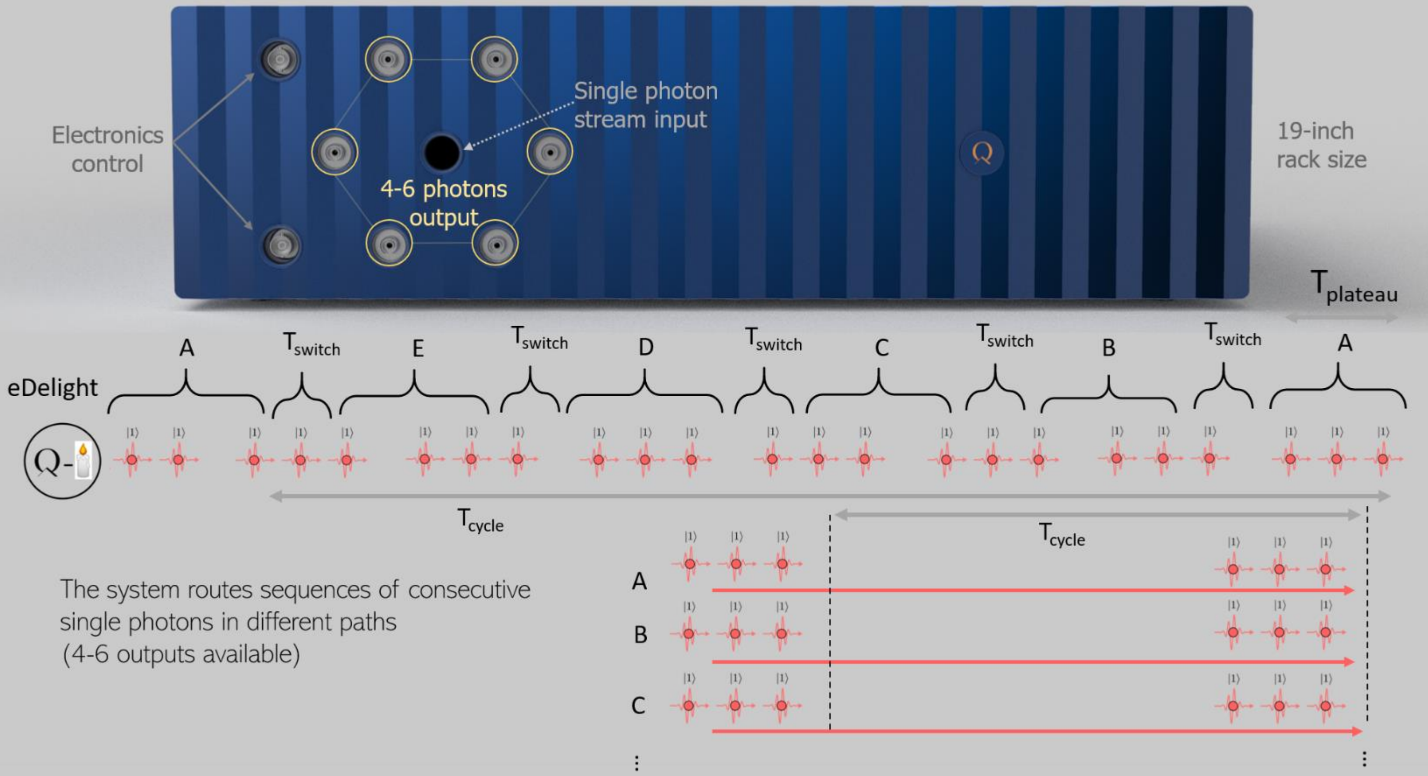
QDmx-n



The first active temporal-to-spatial demultiplexer for quantum applications; it combines optics and electronics in a compact module. Now available for up to 6 photons; adapted to interface *eDelight* with integrated circuits.

Compact, fast and efficient

Single-photon routing towards separate spatial output



The system routes sequences of consecutive single photons in different paths (4-6 outputs available)

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QDmx-n

Specifications

Technology	Proprietary design for the integration of active elements in combination with optics for thigh-speed routing and low transmission losses.
Electrical driving	Output voltage signal (DC)
Number of independent outputs (single mode fiber outputs)	Up to 6 in a single module. Upgrade to 12 outputs available soon.
Optical efficiency *η* (total optical trasnsmission/line)	> 75%
Speed, duty cycle and metrics*	$T_{cycle} \sim 375$ ns, $T_{plateau} \sim 40$ ns, $T_{switch} \sim 35$ ns
Optical and mechanical stability	Limited signal fluctuation over days
Physical dimensions	Height: 150 mm, width: 490 mm, length: 470 mm – weight: < 25 kg (fiber delays not considered)
Electrical connections	100V/120V/230 V, 50 Hz

PLEASE NOTE: for the installation of the fiber delay loops necessary to synchronize the outputs, please contact us.

* From the reported metrics it's possible to calculate the *N (nº of outputs)*-photon coincidence rate at the output of the *QDmx-n.*

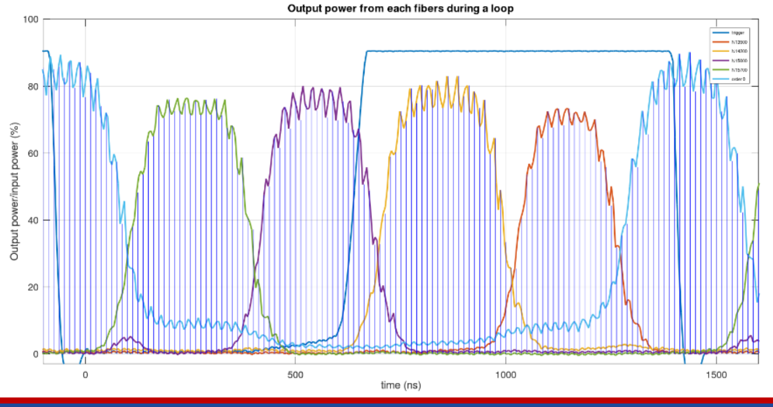
From the values we can extract at first the "Filling factor":

$$FF = N * T_{plateau} / T_{cycle}$$

From which one can calculate the final rate of N coincidences at the output

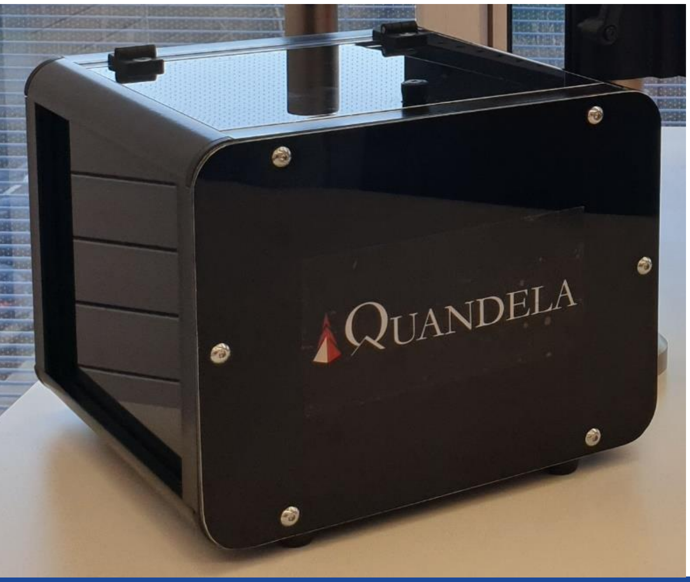
$$rep.rate * FF * \frac{(\eta * Brightness)^N}{N}$$

(*rep. rate* represents the clock rate of the driving excitation laser and *brightness* identifies the *eDelight* source efficiency – previous pages).



Measured QDmx-5 output pulse sequence, synchronized over one full cycle.
Each color represents the output pulse containing a train of single-photons.

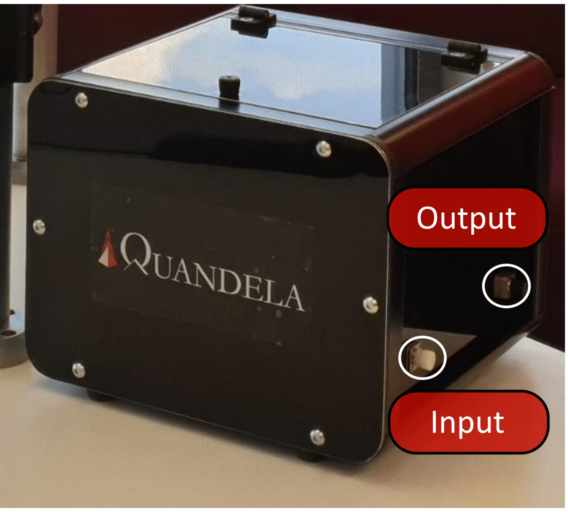
QShaper

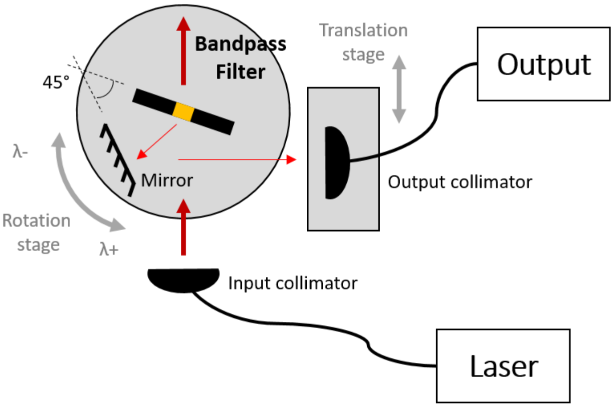


Compact optical setup module comprising a set of customized filters for laser pulse shaping up to 20 picoseconds. Compatible with a variety of pulsed laser systems.

Laser shaping module

Fibered and compact





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QShaper

Specifications	
Technology	Proprietary design and unique optical scheme optimized for *eDelight* single-photon sources optical driving. Compatible with both “near-resonant” and “resonant” driving regimes.
Pulse shaping	Up to 20 picoseconds (different bandwidths available upon request)
Wavelength range	900 nm to 940 nm - adjustable in a continuous way (additional wavelength ranges available upon request)
Input laser	Compatible with femtoseconds (100 fs) or picosecond pulsed lasers
Max input power	20 mW (via SM fiber) 1 W (via free-space)
Stability	< 3% signal fluctuation over days (tested on the shaped laser signal)
Physical dimensions	Height: 200 mm, width: 270 mm, depth: 350 mm - weight: < 2 kg

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The first stand-alone quantum-dot based single-photon source for Quantum Technologies

cryostat, laser system, solid-state single photon sources
and qubit control unit
– all in one system –

Ease of use
Performant
Reliable

Optical Quantum technologies require an increasing stream of quantum particles, identical single photons. On the other hand, most experimental setups require careful optimization for efficient manipulation of the optical signal and analysis of the quantum information.
The revolutionary concept and design of Prometheus' stand-alone single-photon source makes it the optimal solution providing a high rate of single and indistinguishable photons for demanding quantum research.
It consists of an all-in-one device that provides a stable stream of photons with a record brightness thanks to our proprietary technology.
Hence, with Prometheus, researchers can now focus their efforts on their ideas for the design of new experiments based on the manipulation of a large number of optical quantum bits.

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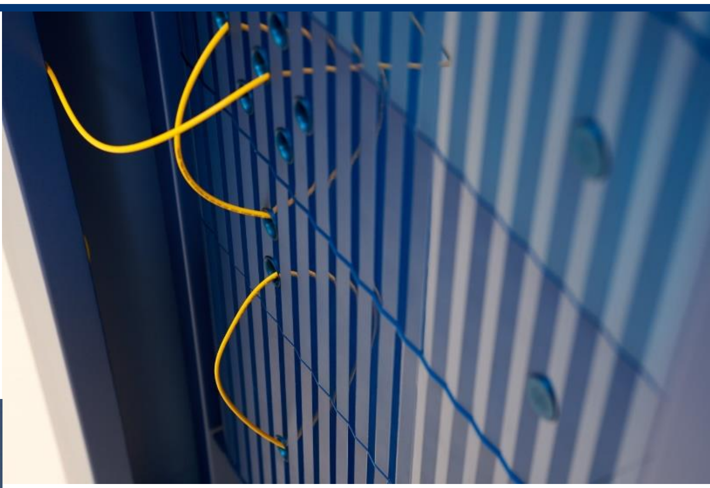
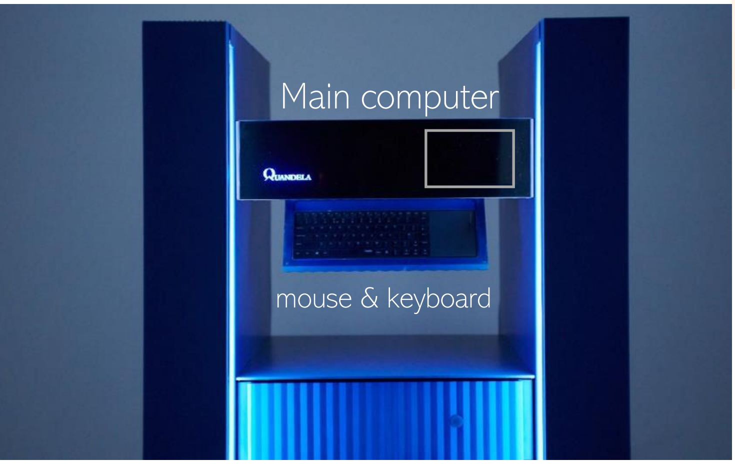
30 cm

1. Main computer
2. Pulsed laser
3. QShaper
4. Single-photon state preparation/ demultiplexer QDmx-6
5. QFiber
6. Cryogenically cooled single-photon sources *eDelight* (pigtailed to a single mode fiber)

2 cm

All the modules are interconnected via optical fibers…





… and controlled via the user interface

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Specifications	
Technology	Proprietary design. Deterministic fabrication of the source devices and optical fiber pigtailing technique.
Emission Wavelength	925 +/- 5 nm 780 nm (available from 2022)
Fibered Brightness* (single-photon emission probability / laser pulse, measured at the fiber output)	> 21% (it corresponds to a single-photon rate of 16 MHz – for 80MHz laser repetition rate)
Single photon purity: $g^2(0)$	< 5% [(1)]
Photon Indistinguishability	> 91% [(2)]
Single-photon bandwidth – emitter lifetime	4.5 (+/- 0.5) GHz , < 150 (+/- 50) picoseconds ''Fourier-transform-limited'' emission
Cool Down Time	15 minutes (40 K) 6 hours (8 K)
Compressor	8 K – Water-cooled. Optional: Air-cooled 40 K – Air-cooled
User Interface	Fully automated control of the different modules using the central computer
Power consumption and electrical connections	8 K : 5 W. 40 K : 1 W. 220V AC
Physical dimensions	Height: 180 mm, Width: 76 mm Depth: 84 mm Weight: 250 kg

*: increase of the single-photon emission rate possible via modification of the laser repetition rate (under request). Continuous wave excitation possible (under request).

1: calculated by "second order correlation measurement g^2" via Hanbury Brown-Twiss interferometer
2: calculated by ''Hong-Ou-Mandel" interference measurements

NOTE: product release in beginning 2022.
Specifications are subject to modifications; to be specified before manufacturing.

Relevant scientific publications:

Controlled and repeatable deterministic fabrication + electrical control + record single-photon indistinguishability & efficient generation

- A. Dousse et al., '[Controlled light-matter coupling for a single quantum dot embedded in a pillar microcavity using far-field optical lithography]'', Phys.Rev.Lett 101, 267404 (2008)
- A. Nowak et al. '[Deterministic and electrically tunable bright single-photon source]', Nature Comm, 5, 3240 (2014)
- N. Somaschi et al. '[Near-optimal single-photon sources in the solid state]', Nature Phot. 10, 340 (2016)
- H. Ollivier et al. '[Reproducibility of high-performance quantum dot single-photon sources]', ACS phot. 2020
- S. Thomas et al. '[Efficient source of indistinguishable single-photons based on phonon-assisted excitation]' arxiv 2007.04330 (2020)

Record cooperativity and highly efficient atom-photon interface:
- V. Giesz et al. '[Coherent manipulation of a solid-state artificial atom with few photons]', Nature comm. 7, 11986 (2016)

Record non-linearity at the single-photon level + photon subtraction & routing configuration
- L. de Santis et al. '[A solid-state single-photon filter]' Nature nanotech. 12, 663 (2017)

Single-photons phase coherence with the driving laser + high photon number purity
- J.C. Loredo et al. "[Generation of non-classical light in a photon-number superposition]" Nature Phot. 13, 803 (2019)

Compatibility and interfacing with an active demultiplexer and other modules for quantum computing applications:
- Anton et al., '[Interfacing scalable photonic platforms: solid-state based multi-photon interference in a reconfigurable glass chip]', Optica 6 (2019)
- D. Istrati et al. '[Sequential generation of linear cluster states from a single photon emitter]', Nature Comm. 11, 5501 (2020)