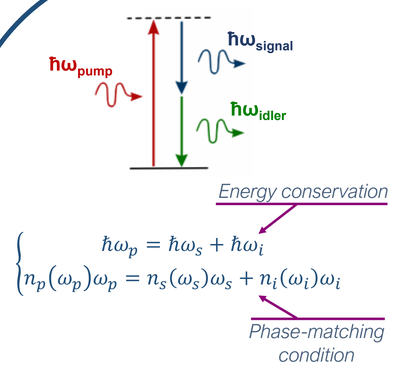
AlGaAs Bragg reflection waveguides for hybrid quantum photonic devices

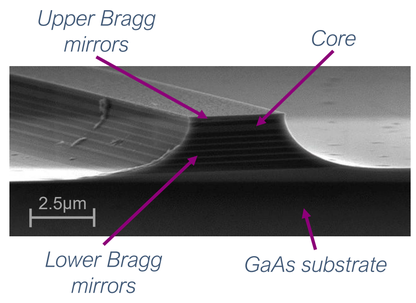
Lorenzo Lazzari [1,2,3], *Jérémie Schuhmann* [1,2,3], *Aristide Lemaître*[2], *Maria I. Amanti* [1], *Frédéric Boeuf* [3], *Fabrice Raineri* [2], *Florent Baboux* [1], *and Sara Ducci* [1]

[1] Laboratoire Matériaux et Phénomènes Quantiques, Université Paris Cité, 75013 Paris, France
[2] Centre de Nanosciences et de Nanotechnologies, Université Paris-Saclay, 91120 Palaiseau, France
[3] ST Microelectronics, 38190 Crolles, France

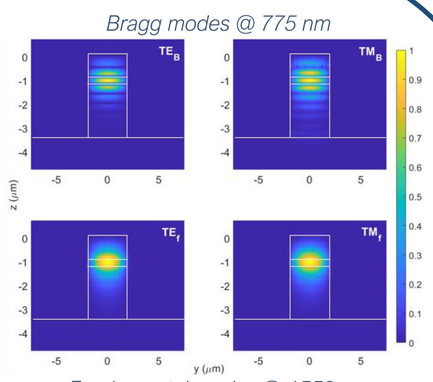
Design & Working Principles



AlGaAs strong $\chi^{(2)}$ can be exploited to generate photon pairs via spontaneous parametric down conversion (**SPDC**)

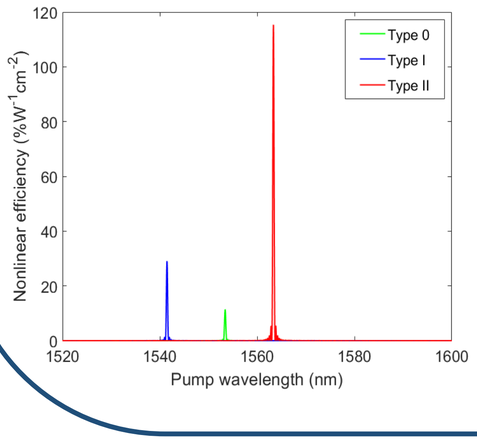


Bragg mirrors are implemented by tuning the aluminium concentraton, to confine two sets of modes



Fundamental modes @ 1550 nm

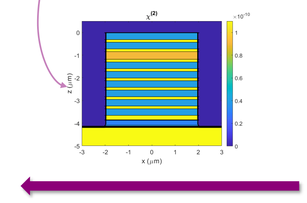
Modal phase-matching (PM) allowing for different conversion processes

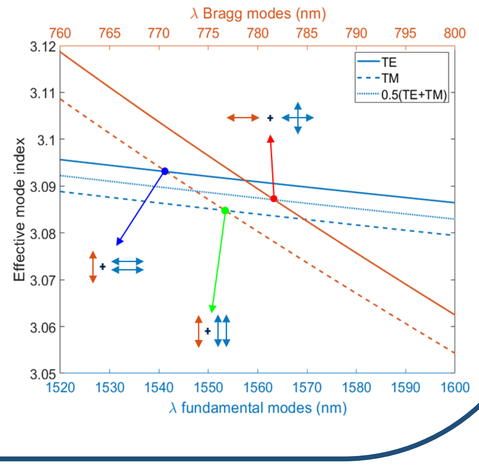


Conversion efficiency:

$$\eta \propto |\Gamma|^2 L^2 \mathrm{sinc}^2(\Delta k L/2)$$

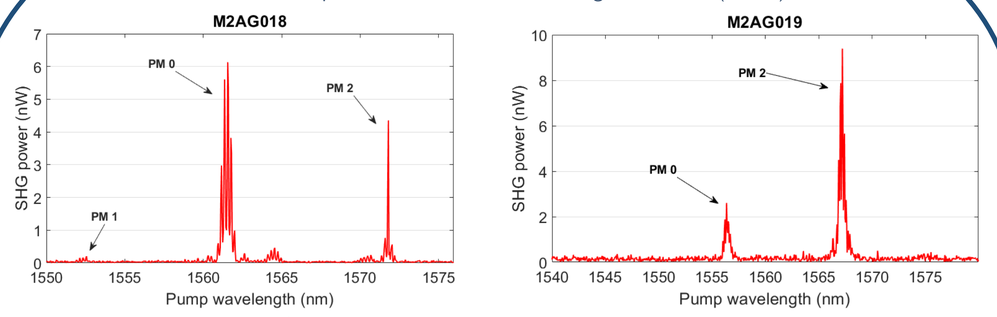
$$\Gamma = \iint_S d(x,z) \times \phi_s^*(x,z)\phi_i^*(x,z)\phi_B(x,z)\mathrm{d}x\mathrm{d}z$$



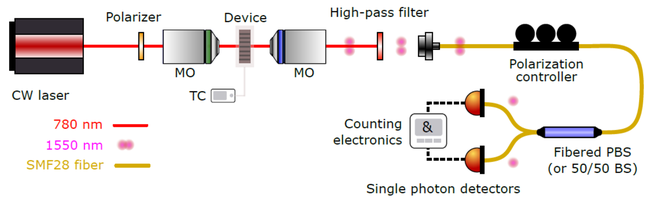


Performances

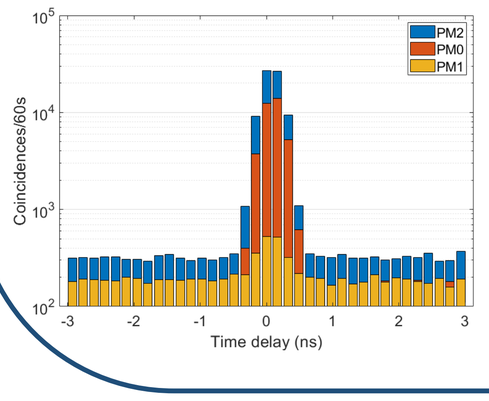
Lock-in amplified second harmonic generation (SHG)

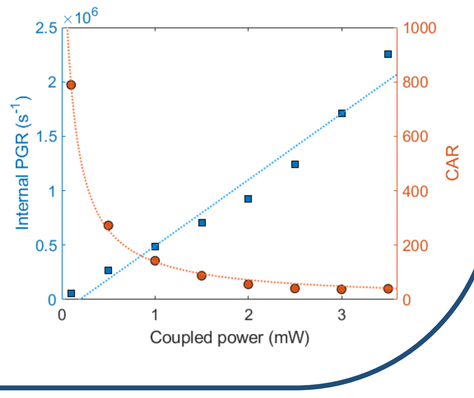


➡ Design validation, fine tuning of parameters

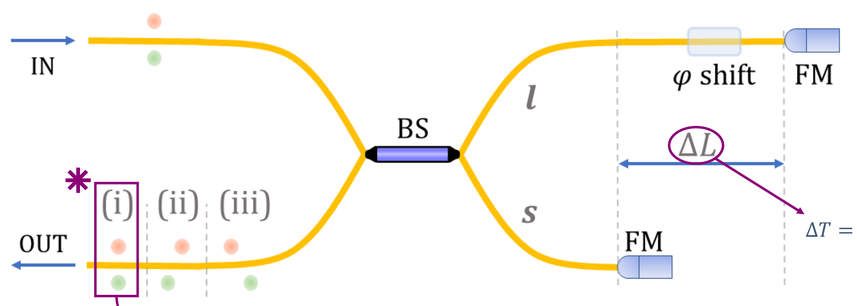


Pair generation rate (**PGR**) measurement

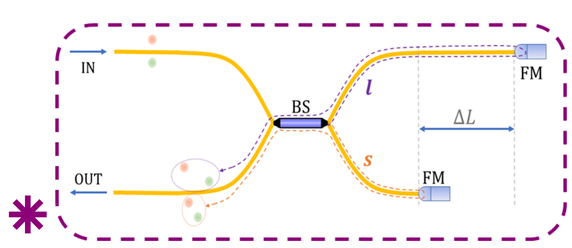




Energy-time entanglement



Fibered **Franson interferometer** in the folded configuration

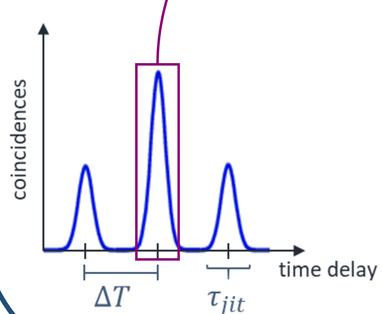


Fibers' **chromatic dispersion** introduces **distinguishability** between the two paths, affecting the entanglement visibility:

$$P(\varphi) = \frac{1}{2} + \frac{1}{2}\iint \mathrm{d}\omega_s \mathrm{d}\omega_i |C(\omega_s,\omega_i)|^2 \times \cos\left\{2\frac{\Delta L}{c}[\omega_s n(\omega_s) + \omega_i n(\omega_i)] + 2\varphi\right\}$$

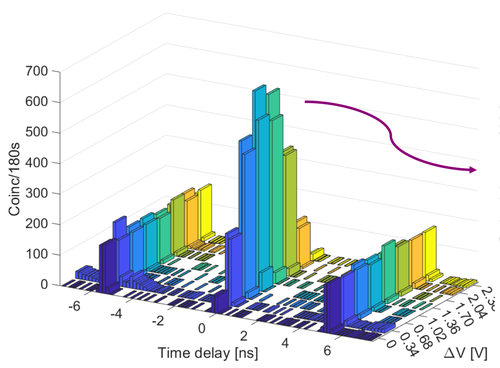
Joint spectral amplitude (JSA)

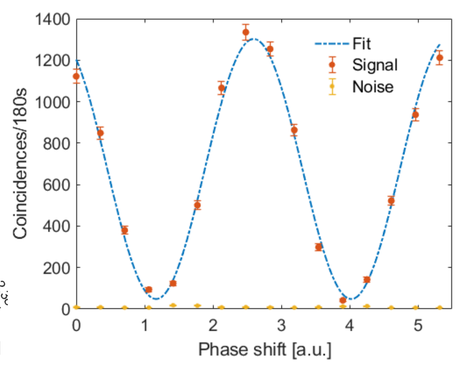
$$|\psi_{A,B}\rangle = \frac{1}{\sqrt{2}}\left(|s_A\rangle|s_B\rangle + e^{i4\varphi}|l_A\rangle|l_B\rangle\right)$$ ➡ Fully entangled state, quantum superpostion

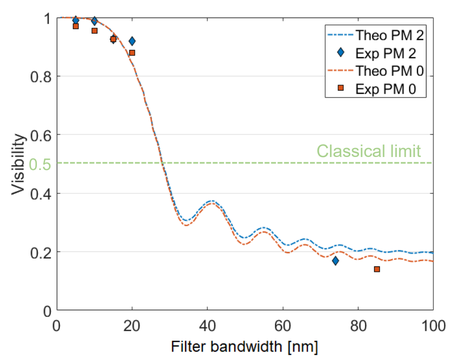


- $\Delta T \gg \tau_c$ → No single-photon interference
- $\Delta T \gg \tau_{jit}$ → Separate case (i) from (ii) and (iii)
- $\Delta T \ll \tau_p$ → To have two-photon interference
- Thermal stability to avoid thermal phase drifts

Results



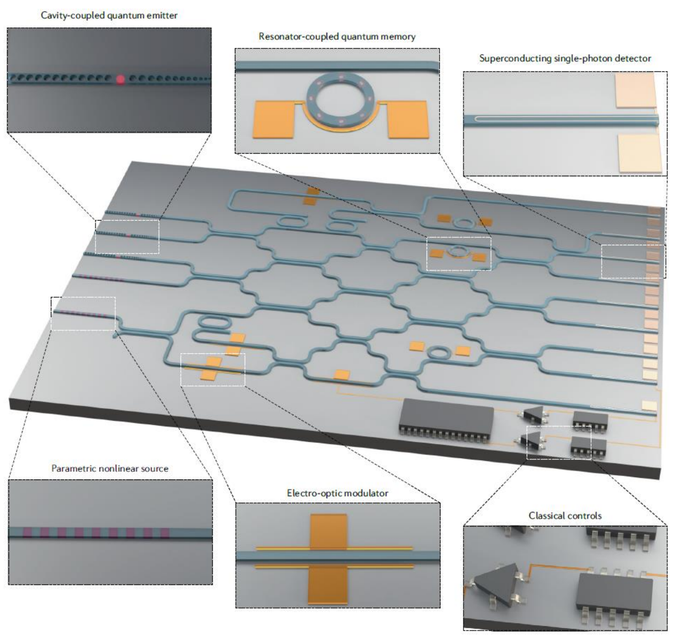




➡ The phase (so the interference profile) is controlled by a piezoelectric fiber stretcher; the visibility is determined by the **entanglement quality:** if >50%, indirect demonstration of energy-time entanglement. With spectral filtering, we demonstrated visibilities up to 99% for both type 0 and 2 PM photon pairs

Towards hybridization

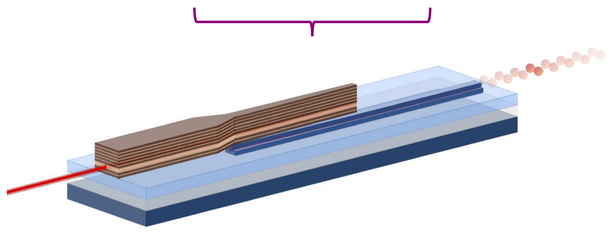
Integrated quantum photonics goal: on-chip generation, manipulation, distribution and detection of qubits



Nature Reviews Physics **4**, 194–208 (2022)

➡ Integrating different platforms to leverage the **complementary assets**

SOI	AlGaAs
✓ Leader in complex linear integrated optical components; CMOS compatibility	✗ Incompatibility with CMOS; complex components still under development
✗ Lack of second order nonlinearity; indirect bandgap	✓ High second order nonlinearity; direct bandgap



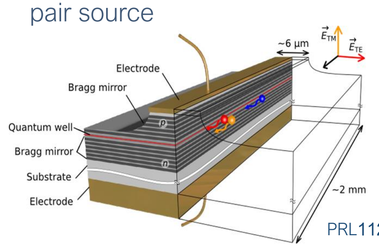
Hybrid AlGaAs/SOI photon-pair source

Challenges

- SOI/AlGaAs wafer bonding, solving the constraints deriving from the lattice mismatch; GaAs substrate removal, waveguide patterning and alignment between the two platforms
- Efficient, wide-band, polarisation insensitive, fabrication friendly, robust and low footprint optical mode coupling design, compatible with existing SOI stacks and industry standards
- Conservation of the produced bi-photon state properties (JSI, entanglement visibility, degree of indistinguishability) from one photonic circuit to the other

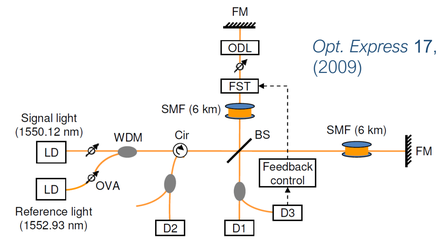
Perspectives

- Integrated hybrid electrically driven photon-pair source



PRL**112**, 183901 (2014)

- Quantum metrology with phase-stabilized Franson interferometer



Opt. Express **17**, 19027 (2009)

- On-chip implementation of QKD protocol based on energy-time entanglement

Financial support: