QUANTEP
QUANtum Technologies Experimental Platform

Call della CSN5 sulle Tecnologie Quantistiche

LNL, MI, Camerino (associati a PG), PI, PV (e UNIMORE), RM2, SA, TO

Realizzazione di una piattaforma comune basata su **Silicon Photonics** per lo sviluppo e caratterizzazione di:

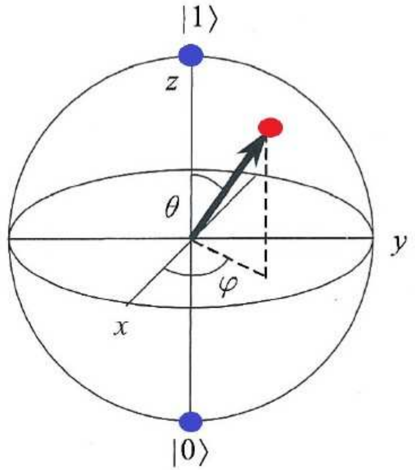
- circuiti per il Quantum Computing, i.e. CNOT (MI, PG, PI, PV, RM2)
- sorgenti di singolo fotone (LNL, TO)
- rivelatori di singolo fotone (RM2, PI, SA, TO)
- circuiti per il controllo della polarizzazione (PV, UNIMORE, RM2)

Finanziato dal 2021 al 2024: ~ 800 kEuro

Personale 2024: 18.7 FTE

Quantum Computing

- 1982: R. P. Feynman (Y. Manin) proposed building a computer based on the manipulation of wavefunctions in order to simulate nature with quantum computer.
- 1994: P. W. Shor suggested an algorithm to factorize integers into prime numbers operating on a quantum computer more efficient than the classical analogue.
- 2001: Knill, Laflamme and Milburn demonstrated how it is possible to use linear optics for quantum information processing using beam splitters, phase shifters, single photon sources and detectors.
- 2001-2002: T. C. Ralph, N. K. Langford, T. B. Bell and A. G. White proposed a NOT-controlled linear optical gate based on coincidence.



$$\alpha_0|0\rangle + \alpha_1|1\rangle, \ |\alpha_0|^2 + |\alpha_1|^2 = 1$$

$|0\rangle$ $|1\rangle$ **computational basis**

Universal Quantum Gates

CNOT: the NAND/NOR gate of Quantum Computing!

1 qubit: $\alpha_0|0\rangle + \alpha_1|1\rangle$, $|\alpha_0|^2 + |\alpha_1|^2 = 1$

$$X = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}$$

Pauli-X (NOT) gate

$$Z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

Pauli-Z gate

$$R_\phi = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\phi} \end{pmatrix}$$

Phase shift gate

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix}$$

Hadamard gate

2 qubits: $a|00\rangle + b|01\rangle + c|10\rangle + d|11\rangle$

$$|a|^2 + |b|^2 + |c|^2 + |d|^2 = 1$$

The prototype 2 qubits gate is the Controlled NOT (CNOT) gate

control bit

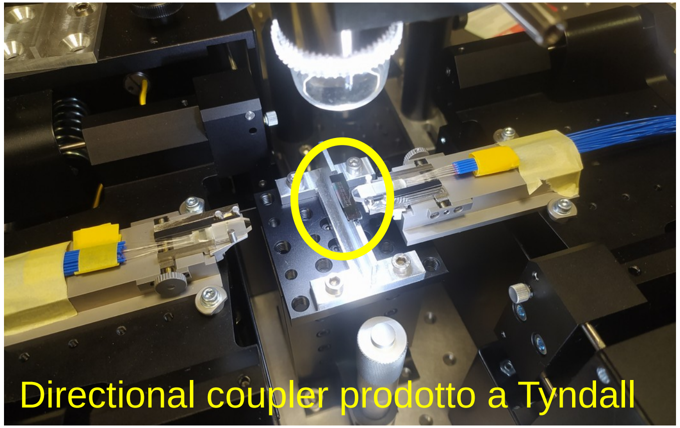
$$\mathrm{CNOT} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

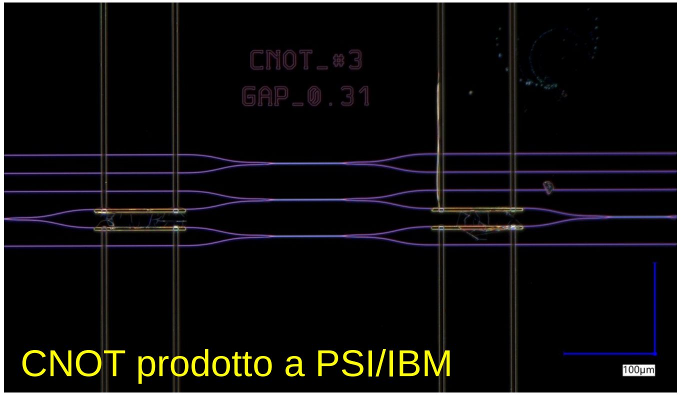
target bit

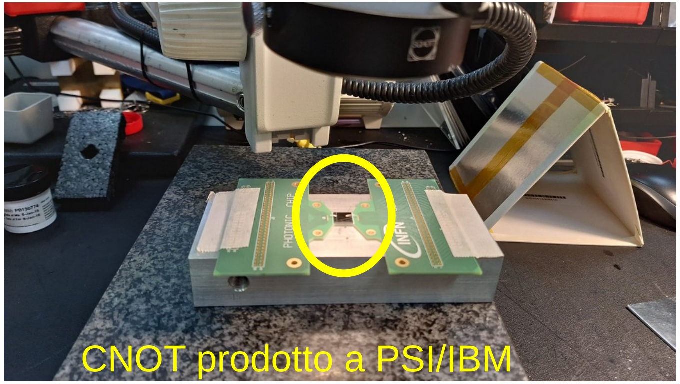
- the control bit is left unchanged
- the output target bit is the XOR of the input control and target bits
- but of course it does much more: it works on the wave function

Circuiti per il Quantum Computing, CNOT gate

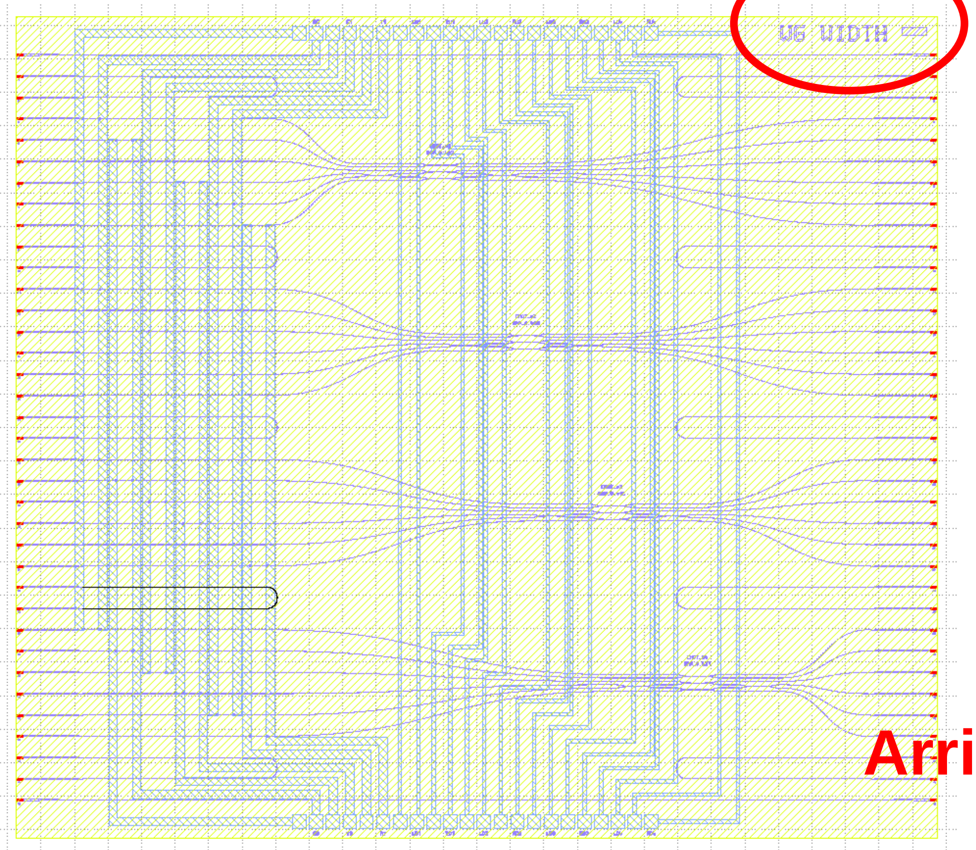
MI, PG, PI, PV, RM2







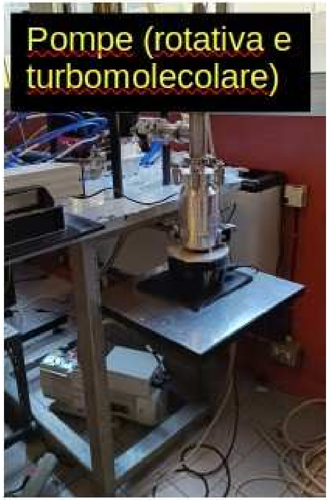
Nuove CNOT da Southampton



Arrivate, montaggio a breve a Pisa

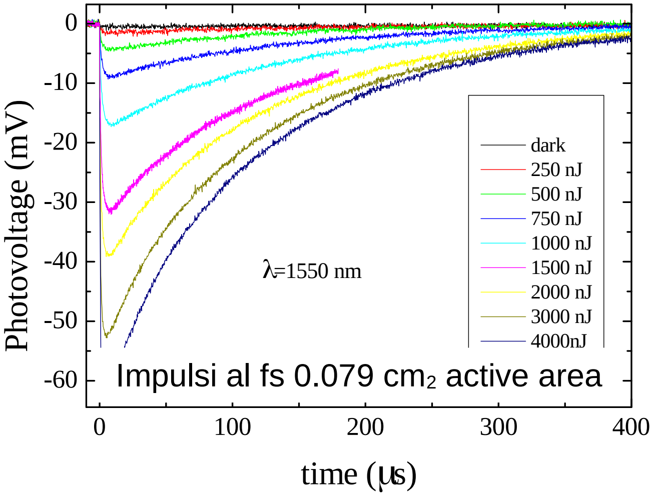
8 variations with 6 nm step, 10 samples, thermal phase shifters, Bragg grating couplers

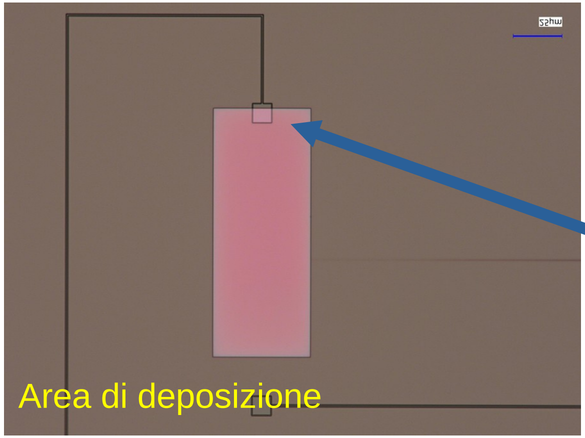
Laboratorio a Tor Vergata

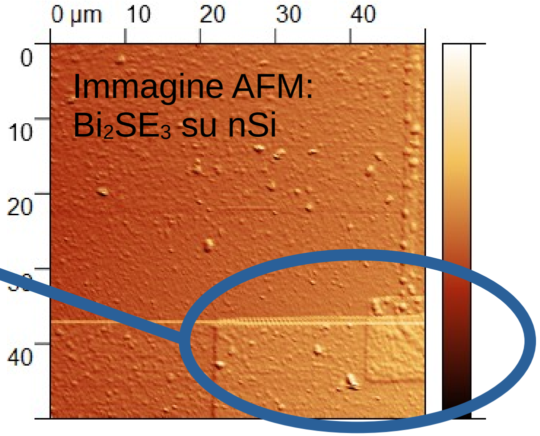


INFN RM2, PI, SA e TO: rivelatori di singolo fotone

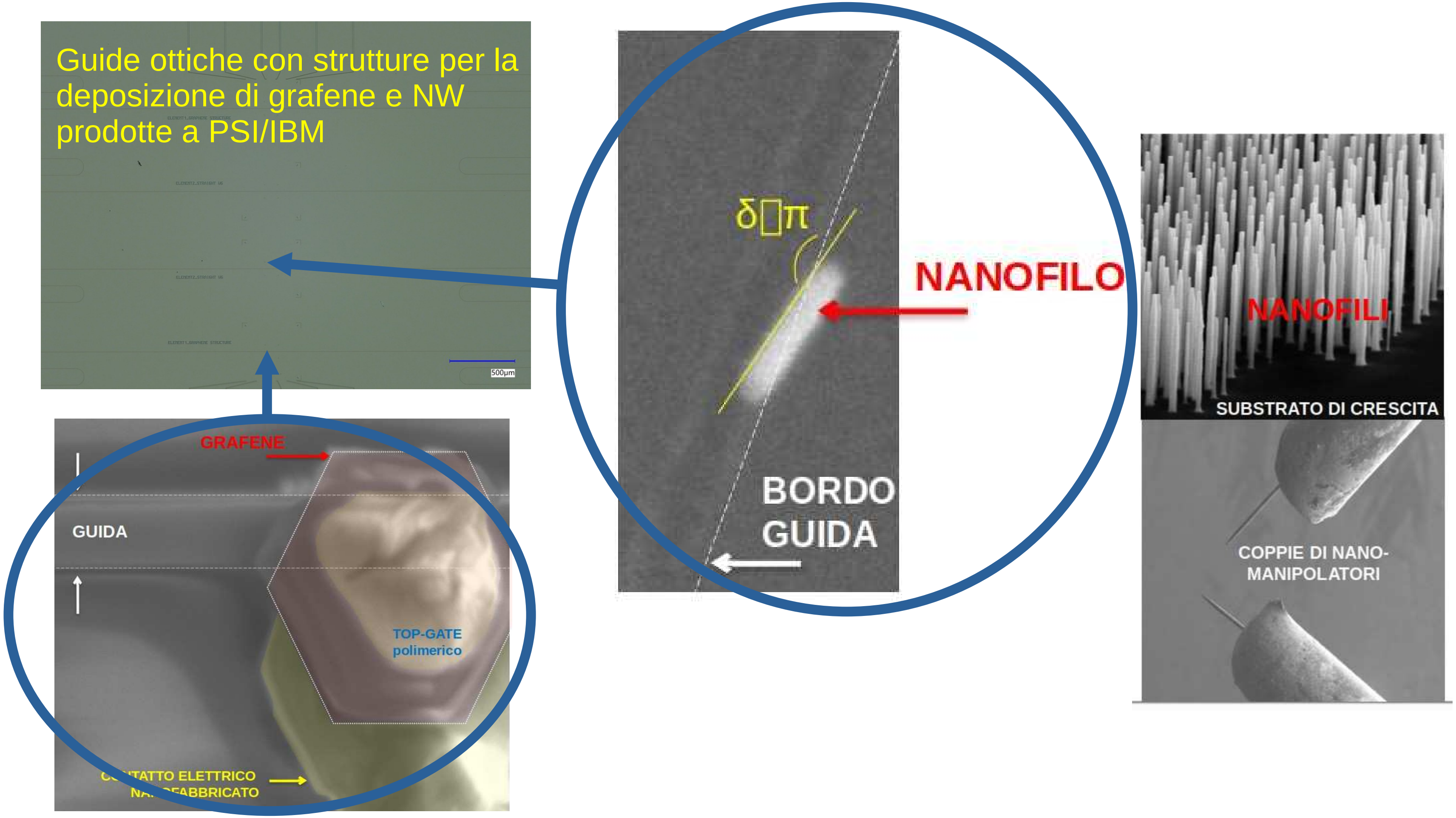
(eterogiunzione Bi_2Se_3 su nSi → bandgap 0.32 eV)







PV, UNIMORE, RM2: controllo della polarizzazione con grafene e nanofili



UNIDET- Universal detector for quantum light (2023-2025)

Andrea Salamon

Trento Institute for Fundamental Physics and Applications

0.4 FTE Mirko Lobino
0.3FTE Paolo Rech
0.2FTE Massimo Cazzanelli
0.2FTE Leonardo Lomongi
0.2FTE Igor Lopez Gonzalez
0.1FTE Alberto Quaranta

Francesco Mattioli
Alessandro Gaggero
Francesco Martini

FONDAZIONE BRUNO KESSLER

Martino Bernard
Gioele Piccoli

Superconducting single photon detectors

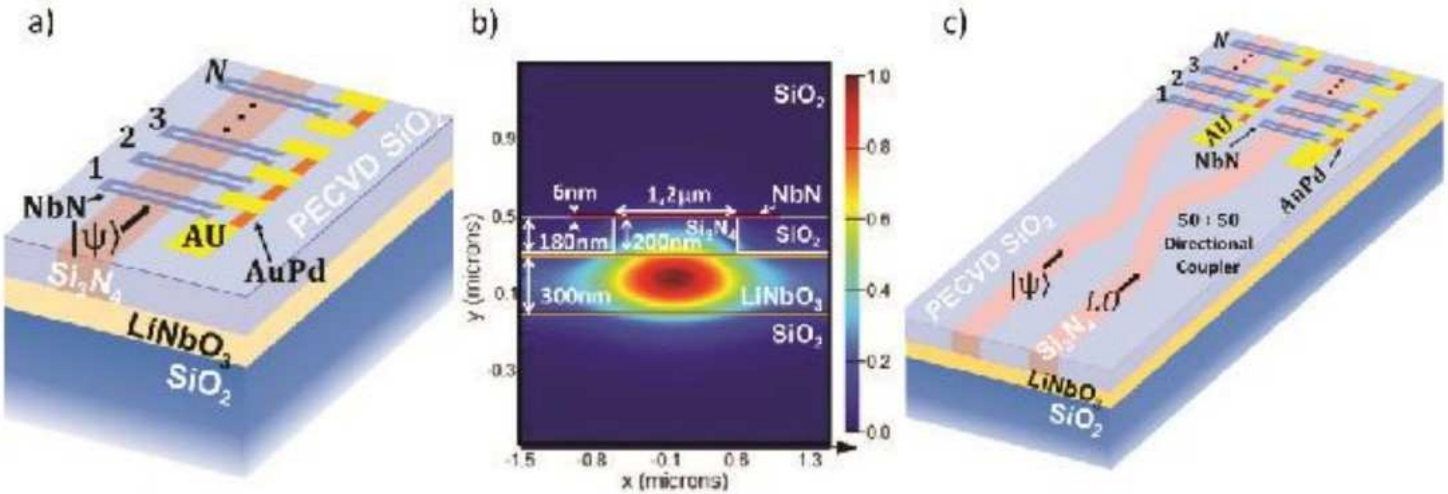
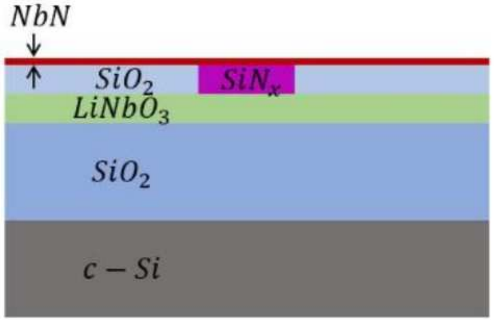
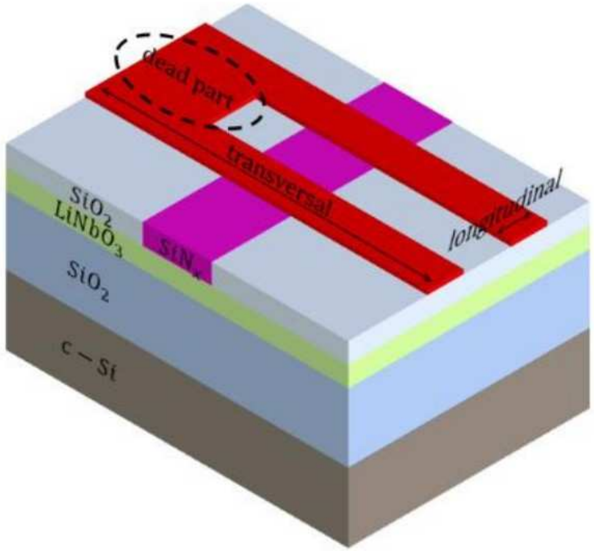


Figure 2 a) Schematic of the integrated PNR to develop in this project showing a series of N pixels composed by a NbN nanowire (80 nm width) and an AuPd on-chip parallel resistance (Rp=20 Ω value). b) Field intensity for the first TE mode propagating in the waveguide where the light absorption in each NbN nanowire element is at 3.4%. c) Schematic of the hybrid detector.

Waveguide and SC structure

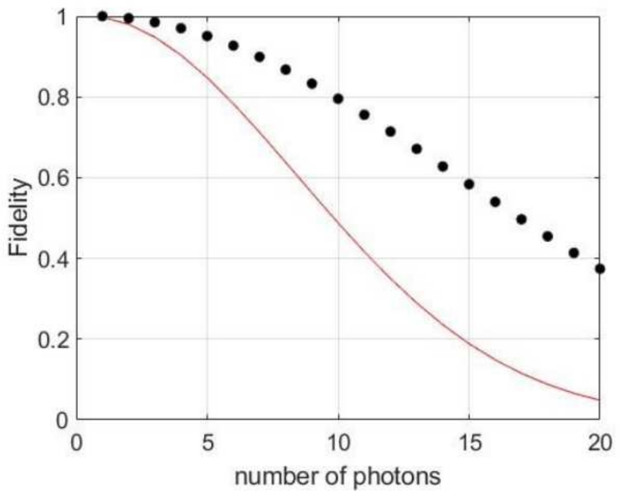
1) Strip loaded configuration
2) Nanomeander of NbN
3) Optimization of the efficiency of each element

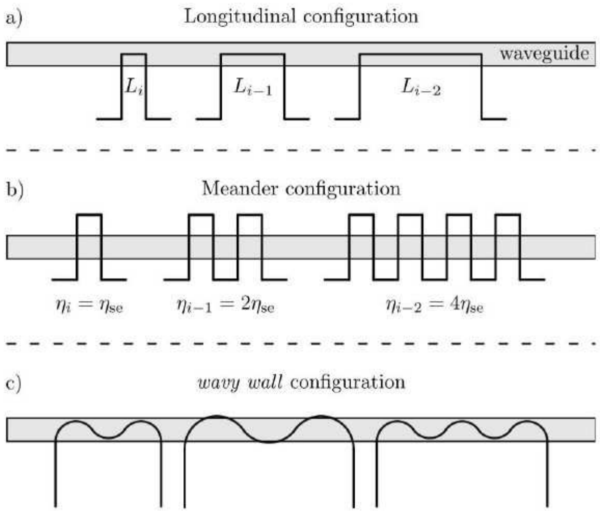




Waveguide and SC structure

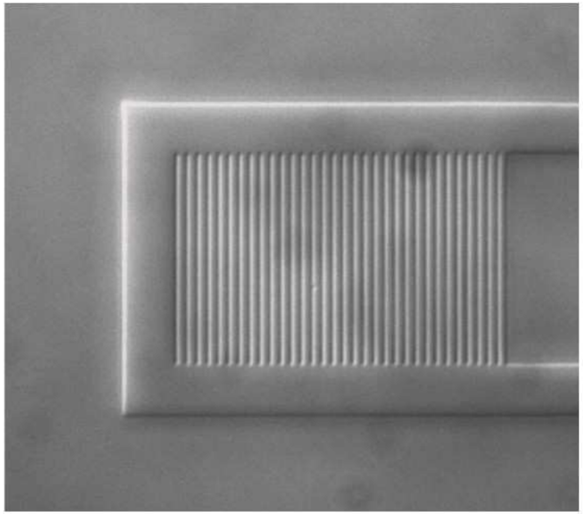
Theoretical simulation of the array
1) Efficiency that grows as 1/n
2) Different configuration studied

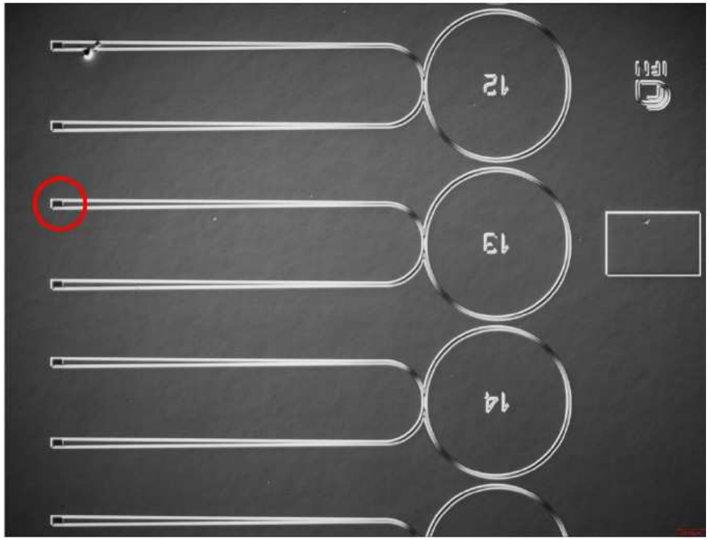




Waveguide fabbricated

1) Waveguides and grating couplers fabbricated
2) 10dB coupling losses and overcoupled structures
3) New fabbriation run on the way





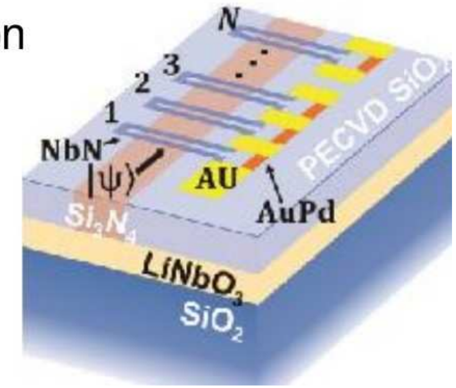
Progress so far and plan for 2024-25

Progress so far:

1) Design of the detector completed: optimized the efficiency of each single element and the photonic part;
2) waveguide fabricated
3) Optimization of the grating couplers

To do in 2024-2025

1) Installation of the cryostat
2) Optimized superconductor film deposition
3) Planarization of the structure
4) Test of home made detectors.



Budget for 2025

struttura	missioni	consumo	inventario	totali
ROMA2 + CNR	6	12		18
TIFPA + FBK	6	15		21
Totale	12	27		39

Criostato per 90kEUR già acquistato nel 2024. Lo strumento verra' usato per la caratterizzazione dei dispositive con sorgenti quantistiche

FTE 2.15 (8 ricercatori) + 0.2 (1 tecnico)

INFN Quantum Cryptography Iniziative

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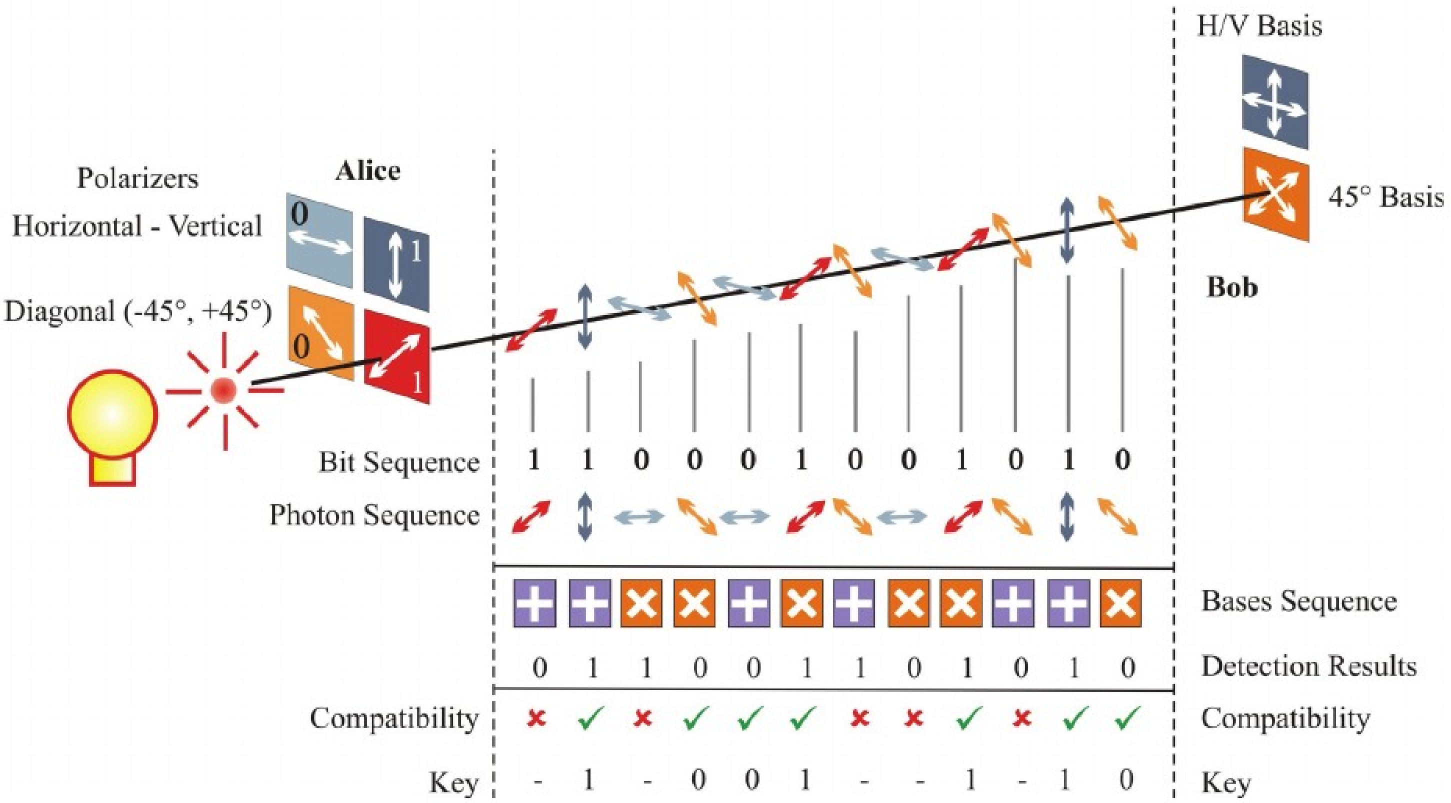
INFN Quantum Cryptography Iniziative

Title: |IQ><CI| - INFN Quantum Cryptography Iniziative
Duration: Three years
Research Field: Detectors & Electronics
Principal Investigator: Andrea Salamon, INFN Sezione di Roma Tor Vergata
Research Units: BA, LNL, PG, PI, PV, RM2, TIFPA, TO

Quantum Key Distribution: the BB84 protocol



QKD con fotoni entangled e sincronizzazione

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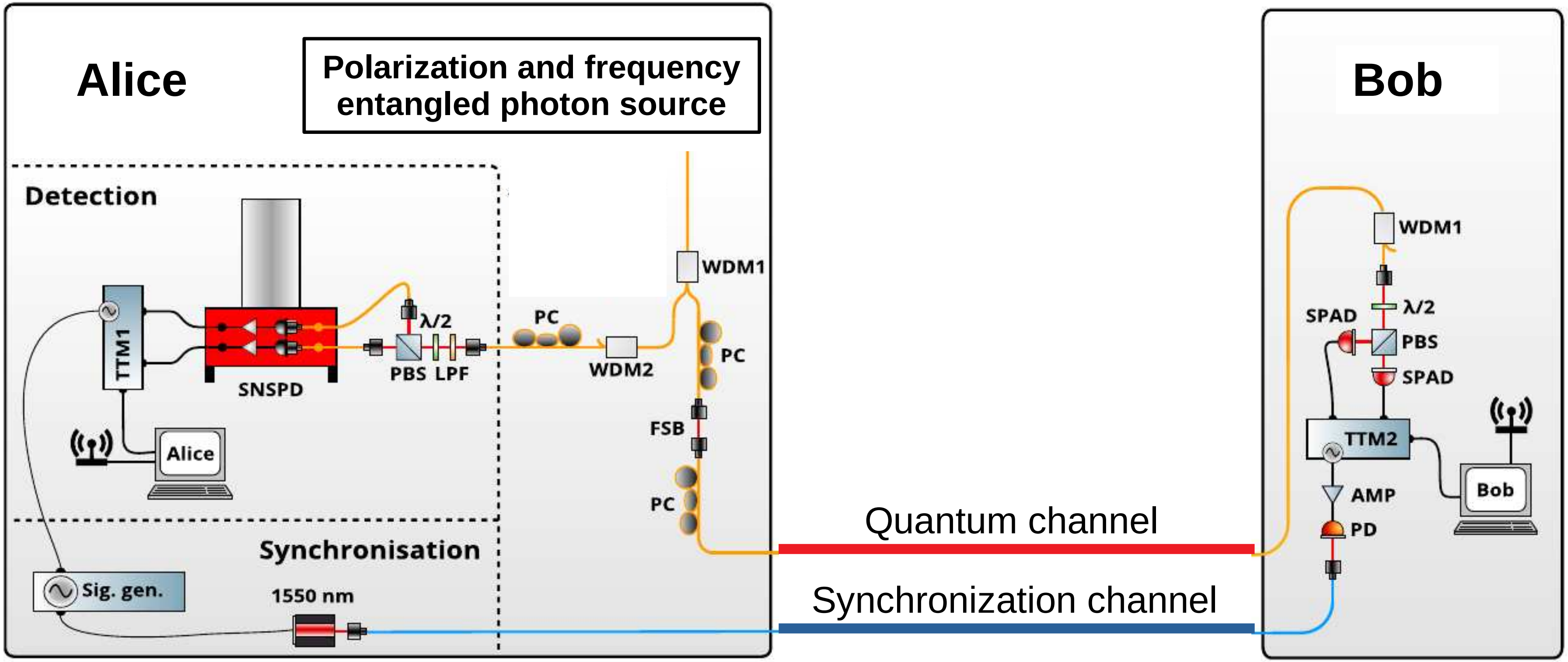
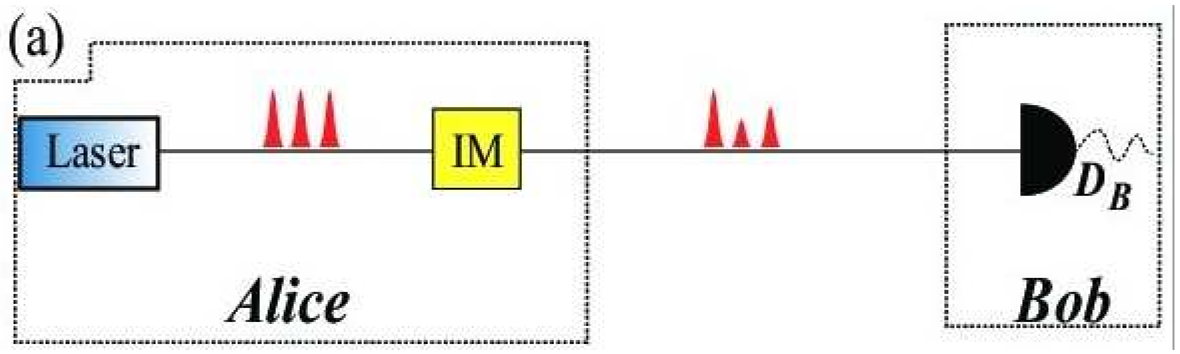


Con componenti bulk, sorgente e rivelatore disponibili da QUANTEP

I fotoni vengono separati in frequenza (ma rimandgono entangled in polarizzazione). Uno viene usato per fare la QKD e l'altro per la sincronizzazione.

BB84 con laser impulsato attenuato - decoy states



INFN Quantum Cryptography Iniziative

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Sezioni/laboratori coinvolti: BA, LNL, PG, PI, PV, RM2, TIFPA, TO

Durata: 3 anni

ATTIVITÀ:

- WG1 Integration and coordination e QKD bulk (sections: all; coord: RM2)
- WG2 Theory (sections: BA, PV; coord: BA)
- WG3 Silicon photonics and integrated devices manufacturing (LNL, PG, PI, RM2, TO; coord: PI)
- WG4 Photon Number Resolving detectors manufacturing (RM2, TIFPA; coord: RM2-CNR-IFN)
- WG5 Electronics (PI, RM2, TIFPA; coord: TIFPA)

FTE e richieste di finanziamenti

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Research Unit	Full Time Equivalents		
	2025	2026	2027
Bari	1.0	1.0	1.0
LNL	1.6	1.2	1.2
Perugia	1.9	1.9	1.9
Pisa	1.0	1.0	1.0
Pavia (Bellani)	1.2	1.2	1.2
Pavia (Borghi)	1	1	1
Pavia (Chesi)	1	1	1
Roma TV	4.5	4.5	4.5
TIFPA	1.0	1.0	1.0
Torino	2.5	2.5	2.5
TOTAL	x.x	x.x	x.x

~ 17 FTE

Contributi da PNRR e PNR!
A Tor Vergata:
- **nuovo tavolo ottico**
- **nuovo cryocooler per i test**
- **strumentazione ottica varia**

Unit	Item	2025	2026	2027	Description
BA	Travel	6	6	6	Collaboration and common tests
LNL	Travel	4	4	4	Collaboration and common tests
	Cons	8	8	4	Laboratory consumable (single photon sources)
PG	Travel	6	6	6	Collaboration and common tests
	Cons	6	6	4	Laboratory consumables (polarization control devices)
PI	Travel	6	6	6	Collaboration and common tests
	Cons	15	15	10	Cleanroom consumables
	Cons	3	3	2	Laboratory consumable
PV	Travel	6	6	6	Collaboration and common tests
	Cons	6	6	4	Laboratory consumables (polarization control devices)
	Cons	6	6	4	Laboratory consumables (optical fibers, v-groove, filters, …
RM2	Travel	6	6	6	Collaboration and common tests
	Cons	3	3	3	Laboratory consumables (optical fibers, v-groove, filters, …
	Cons	6	6	4	Laboratory consumables (single photon detectors)
	Cons	8	8	4	EBL usage (200 EUR/h 40 h/year) at CNR-IFN
	Cons	5	5	3	Cleanroom consumables (resist, metals, …) at CNR-IFN
	Cons	2	2	2	Laboratory consumables at CNR-IFN
	Equip	8			DWDM MUX and DEMUX
	Equip	35			Polarization controllers, beam splitters, filters, ecc
TIFPA	Travel	6	6	6	Collaboration and common tests
	Cons	2	2	2	Laboratory consumables (electronics)
	Cons	3	3	3	Laboratory consumables (optical fibers, ecc)
	Equip	8			FPGA evaluation board for fast data acquisition
	Equip	25			PNR detector with accessories (contribution)
TO	Travel	6	6	6	Collaboration and common tests
	Cons	6	6	4	Laboratory consumables (single photon sources)
TOTAL		201	125	99	

Last but not least

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Forte interesse da parte del MIMIT

Firmata una letter of intent

Laboratori molto attrezzati

Una linea di test dedicata dalla sede dell'EUR a Pomezia, interessantissima per esperimenti di "entanglement distribution", protocollo Eckert 91 (un altro protocollo di QKD basato sulle disuguaglianze di Bell) e per esperimenti sulle disuguaglianze di Bell! Da riparare...