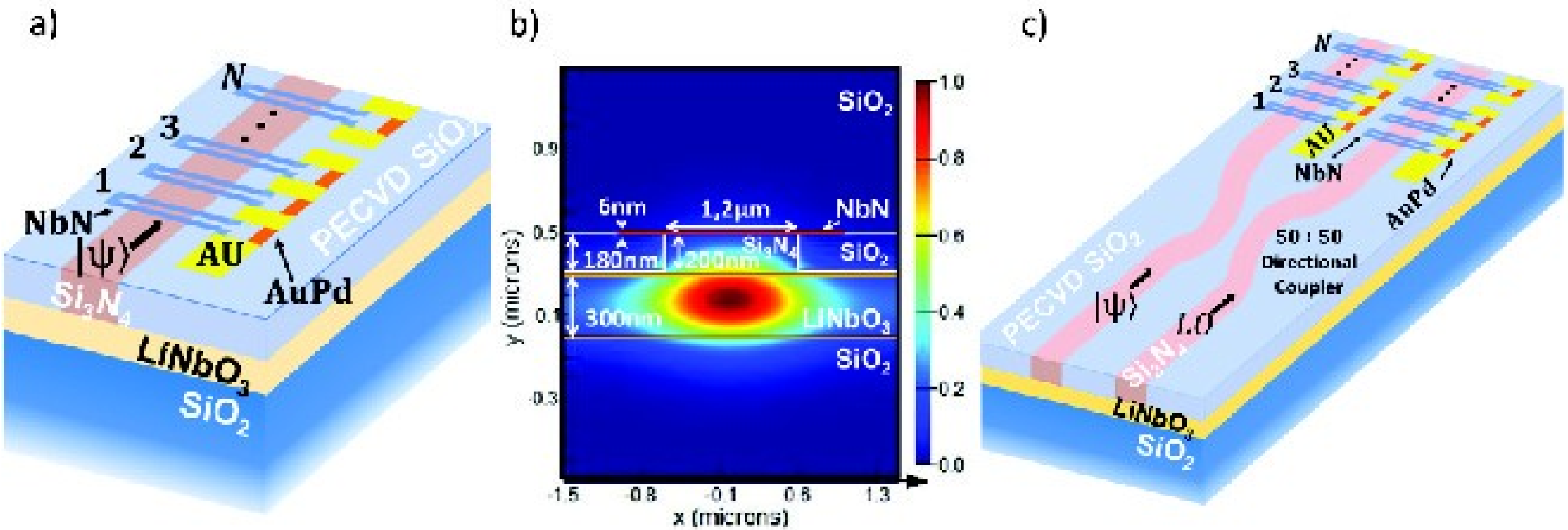
UNIDET- Universal detector for quantum light (2023-2026, estensione)



INFN
CNR IFN
FBK FONDAZIONE BRUNO KESSLER
TIFPA Trento Institute for Fundamental Physics and Applications

The team

Andrea Salamon 20%
Thu Ha Dao 50%

Mirko Lobino
Paolo Rech
Massimo Cazzanelli

Leonardo Lomongi
Igor Lopez Gonzalez
Alberto Quaranta

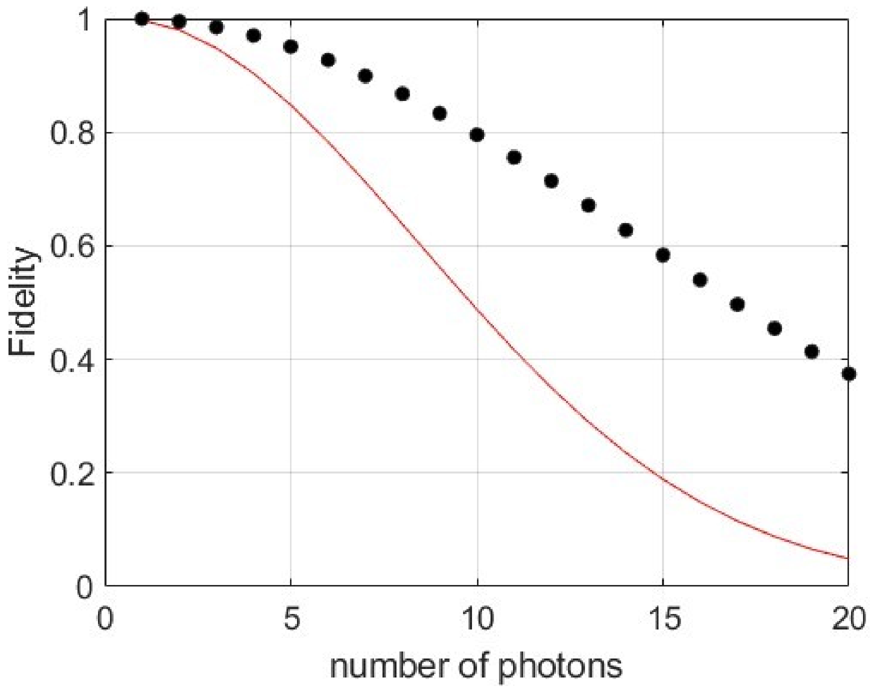
Francesco Mattioli 20%
Alessandro Gaggero 20%
Francesco Martini 20%

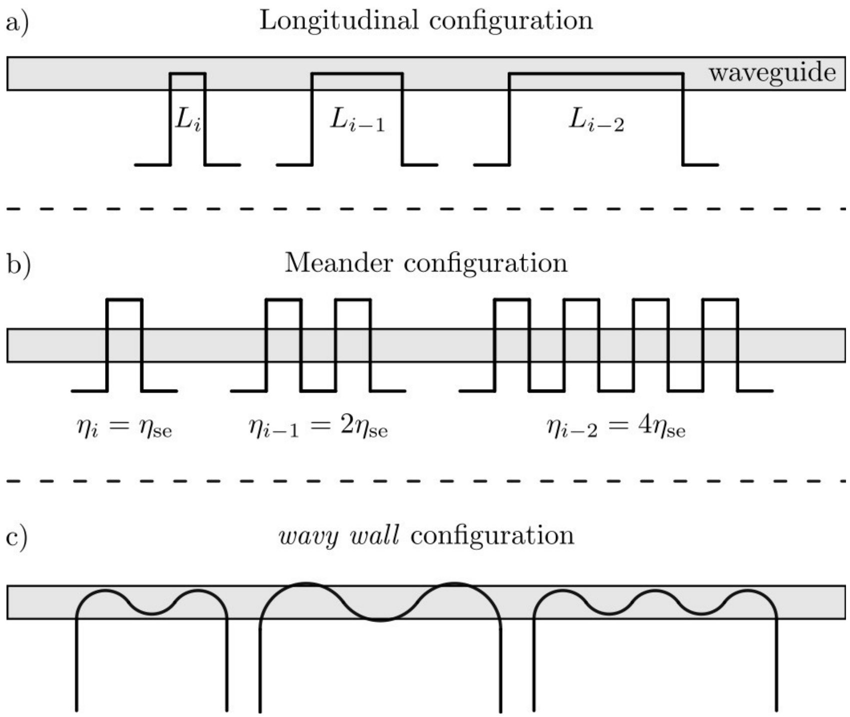
Martino Bernard
Gioele Piccoli

Waveguide and SC structure

Theoretical simulation of the array

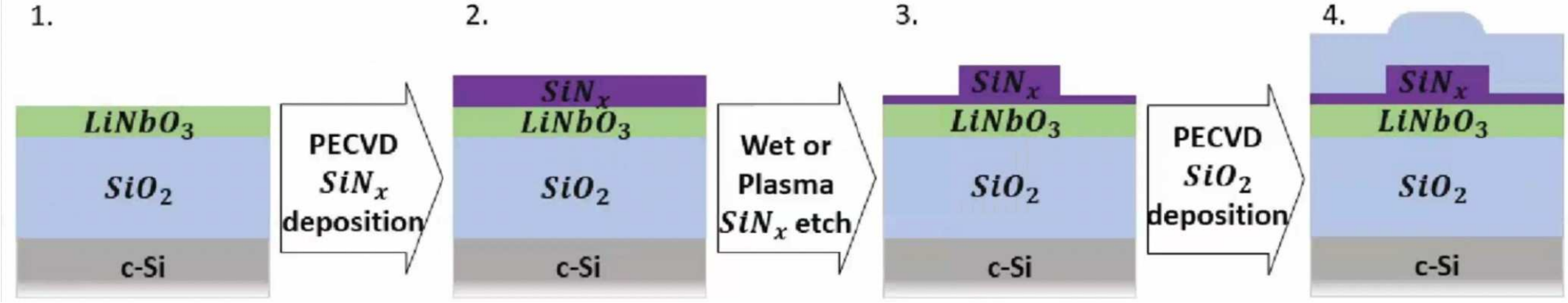
1) Efficiency that grows as 1/n
2) Different configuration studied
3) L. Limongi,et al, Optics Communications 575, 131244 (2025)

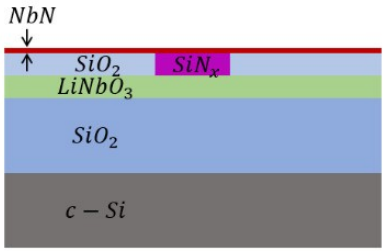


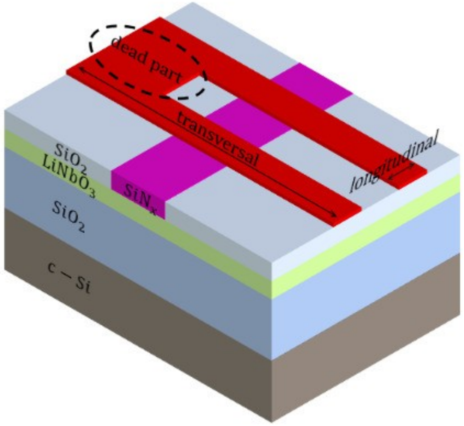


Waveguide and SC structure

1) Strip loaded configuration
2) Nanomeander of NbN
3) Optimization of the efficiency of each element
4) Planarization to be done by ErzTM in Germany

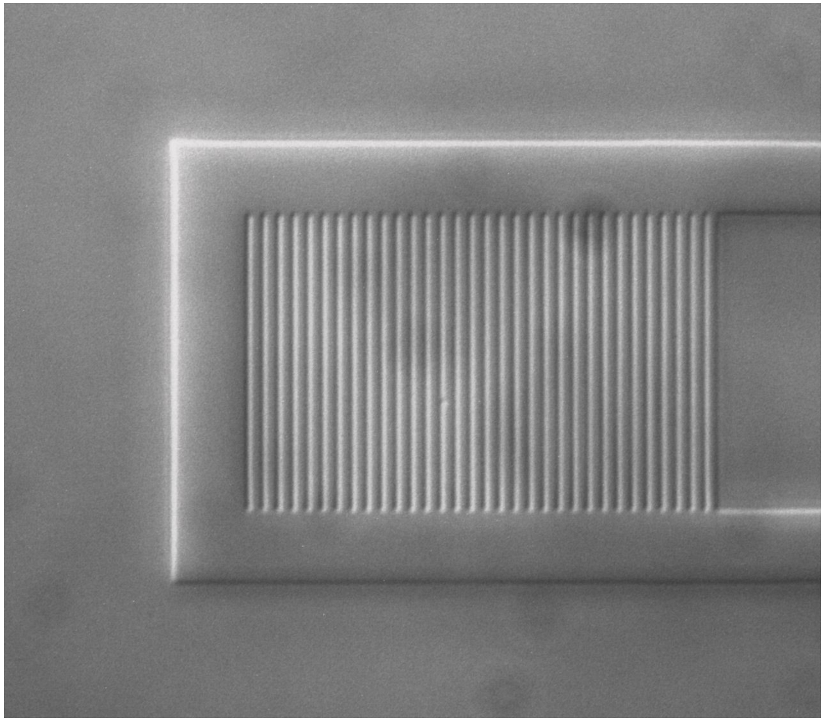


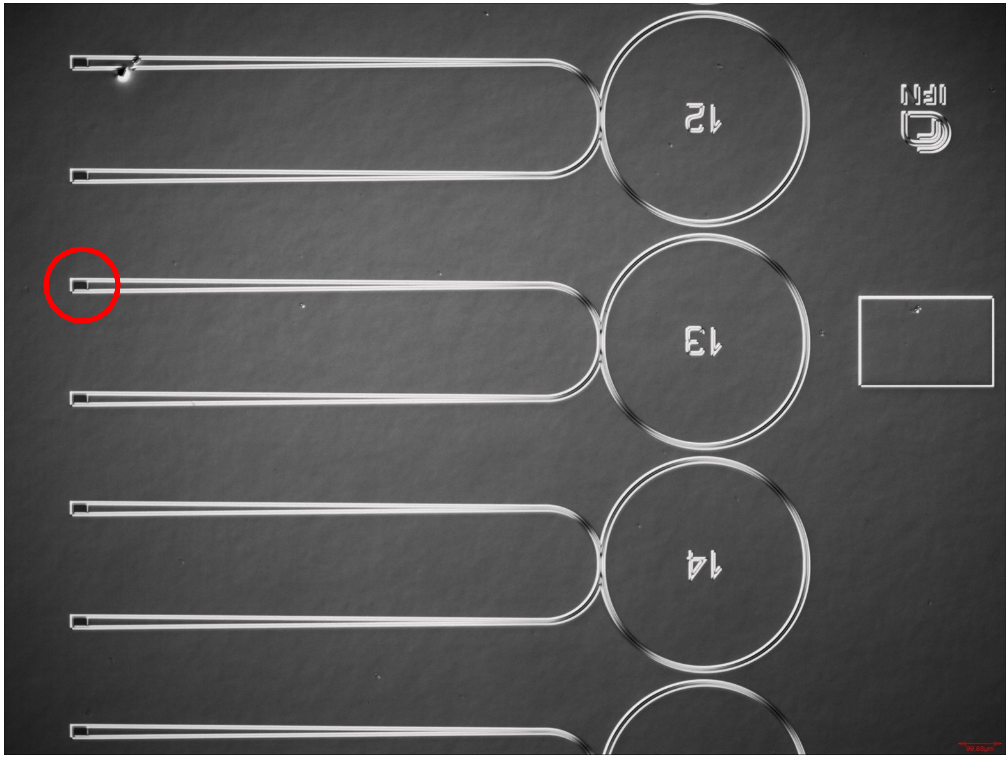




Waveguide fabbricated

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

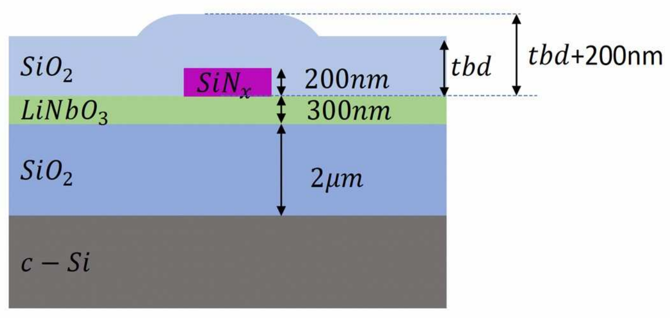




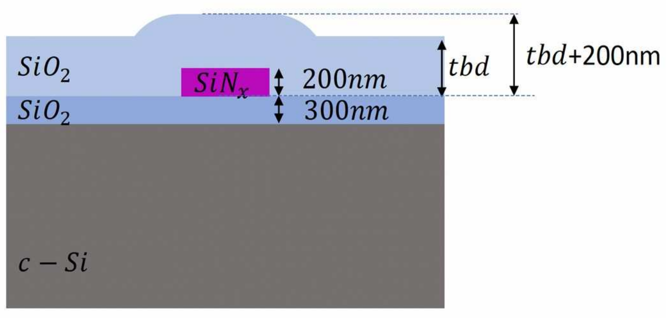
Current status and reasons for extension

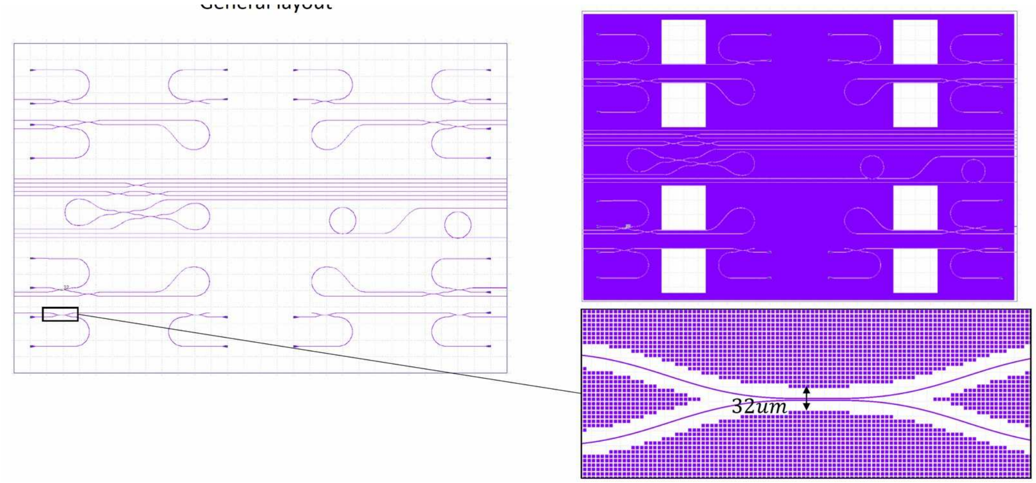
1) Samples sent to Germany
2) Dummy dices and real samples
3) Ready around September

Real samples



Dummy dices





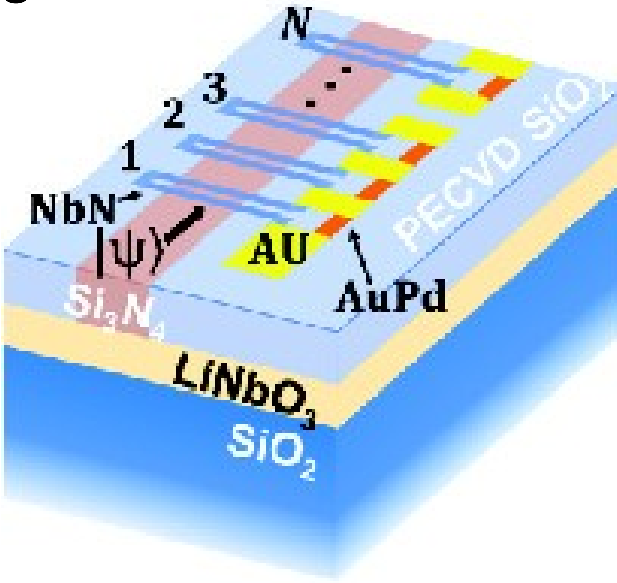
Progress so far and plan for 2025-26

Progress so far:

1) Planarization of the structure (outsourced)
2) Optimized superconductor film deposition
3) Squeezed vacuum source for characterization

To do in 2026

4) Packaging of the devices
5) Test of home made detectors with laser light
6) Test with quantum source
7) Synergy with UPHOS (new experiment)



Richieste finanziarie 2026

2000 Consumabili clean room CNR-IFN
1000 PCB di test
1000 Componenti PCB e cavi per installazione nel cryocooler
1000 Due fiber array
1000 Fibre ottiche varie
1000 Due polarizzatori a tre pad, connettori FC/APC
1500 Display misuratore di pressione Leybold
2000 Missioni

10500

UPHOS- **U**ltrafast **PHO**tonics for quantum **S**imulation (2026-2028)

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IFN

UNIVERSITÀ DI PAVIA

TIFPA

Trento Institute for Fundamental Physics and Applications

The team

Pavia unit

Member	Age	FTE
D. Bajoni	49	0.7
M. Borghi	37	0.5
M. Galli	56	0.5
M. Liscidini	47	0.5
Total FTEs		**2.2**

Roma Tor Vergata unit

Member	Age	FTE
F. De Matteis	63	0.2
A. Gaggero	46	0.5
C. Marin	29	0.3
F. Martini	37	0.5
F. Mattioli	51	0.2
P. Piergentili	37	0.2
A. Rengarajan	28	0.5
A. Salamon	55	0.7
Total FTEs		**3.1**

TIFPA unit

Member	Age	FTE
H. Hasnaoui	29	0.2
L. Limongi	26	0.3
M. Lobino	48	0.2
I. Lopez Gonzalez	33	0.3
A. Quaranta	61	0.2
P. Velha	44	0.3
Total FTEs		**1.5**

UNIVERSITÀ DI PAVIA

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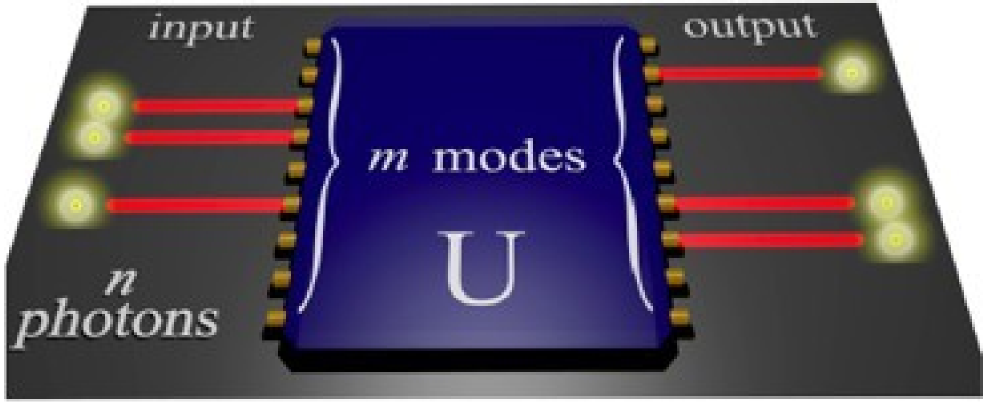
Boson Samplig

What is boson sampling

1) Interfering n bosons in a network of m modes;
2) Calculating the probability of a certain distribution output is hard.



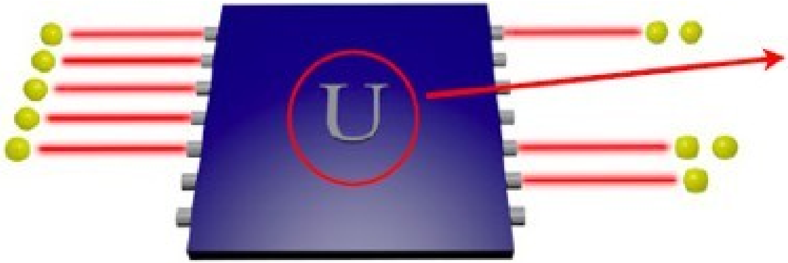
Photons naturally solve the BosonSampling problem

F. Sciarrino, Lecture on boson sampling, https://www.sif.it/media/2e2d8d06.pdf

Boson Samplig

Sampling the output distribution (*even approximately*) of non-interacting bosons evolving through a linear network is hard to do with classical resources

n bosons
m modes



Uniformly drawn

Why? Transition amplitudes are related to the permanent of square matrices

$$\langle T|U_F|S\rangle = \frac{\mathrm{Per}(U_{S,T})}{\sqrt{s_1!\dots s_m!t_1!\dots t_m!}}$$

$$\mathrm{Per}(A) = \sum_{\sigma\in S_n}\prod_{i=1}^{n} a_{i,\sigma_i}$$

classicaly hard

input

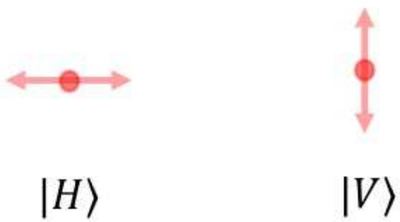
$$\text{output}\quad \begin{array}{c} \\ 0\\1\\1\\1\\0 \end{array}\begin{array}{c} \begin{array}{ccccc} 0 & 1 & 1 & 0 & 1 \end{array} \\ \begin{pmatrix} 0.212 & -0.018+0.165i & -0.238-0.18i & -0.429+0.32i & -0.715+0.2i \\ -0.193-0.388i & -0.045-0.379i & 0.19+0.311i & 0.328-0.269i & -0.594+0.03i \\ -0.723+0.363i & 0.087-0.09i & -0.076-0.155i & 0.206+0.443i & -0.153-0.193i \\ -0.092+0.045i & -0.148-0.645i & -0.588+0.184i & -0.369-0.086i & 0.167+0.025i \\ 0.318-0.009i & -0.144-0.594i & 0.452-0.405i & 0.037+0.387i & 0.071+0.025i \end{pmatrix}\end{array}$$

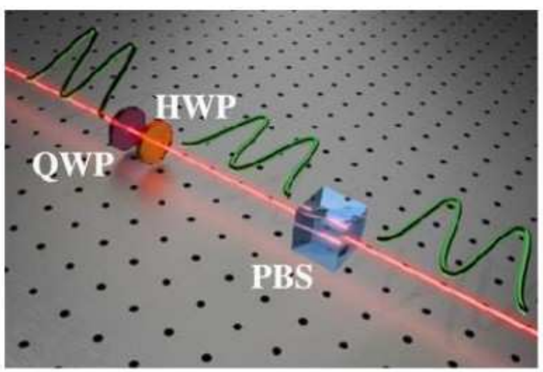
S. Aaronson and A. Arkhipov, Proceedings of the 43rd Annual ACM Symposium on Theory of Computing, 333–342

F. Sciarrino, Lecture on boson sampling, https://www.sif.it/media/2e2d8d06.pdf

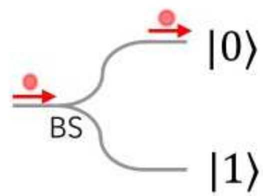
Choice of the best degree of freedom

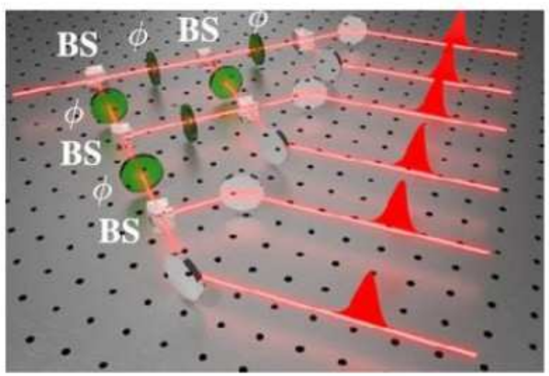
Polarization



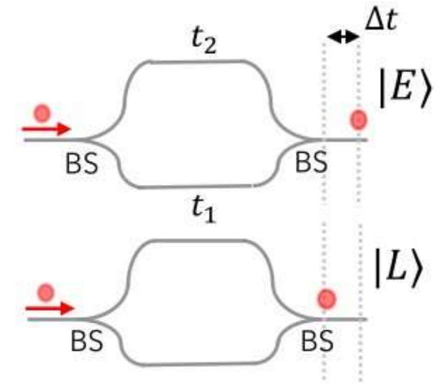


Path

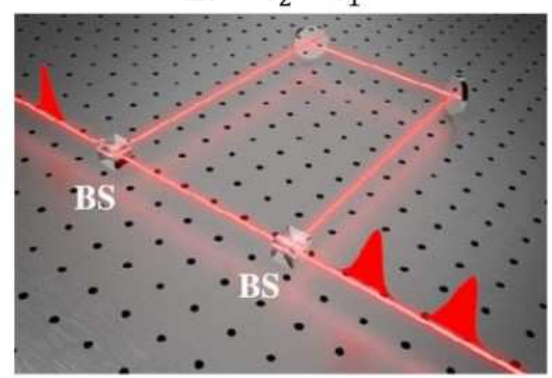




Time-bin

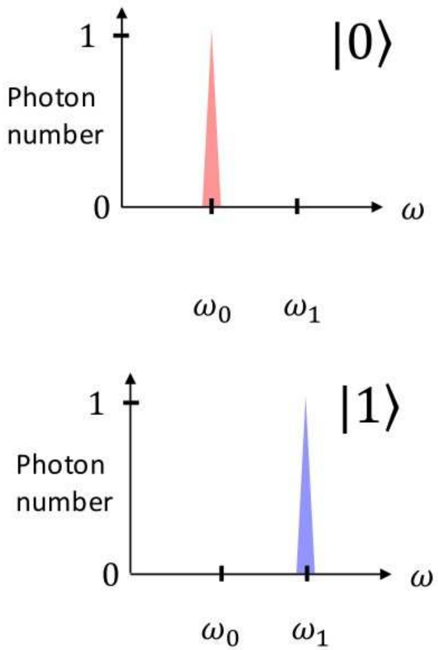


$\Delta t = t_2 - t_1$

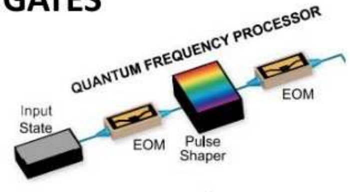


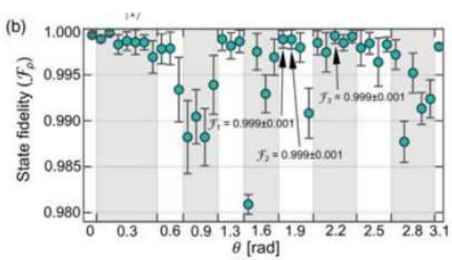
Choice of the best degree of freedom

Frequency-bin encoding



GATES



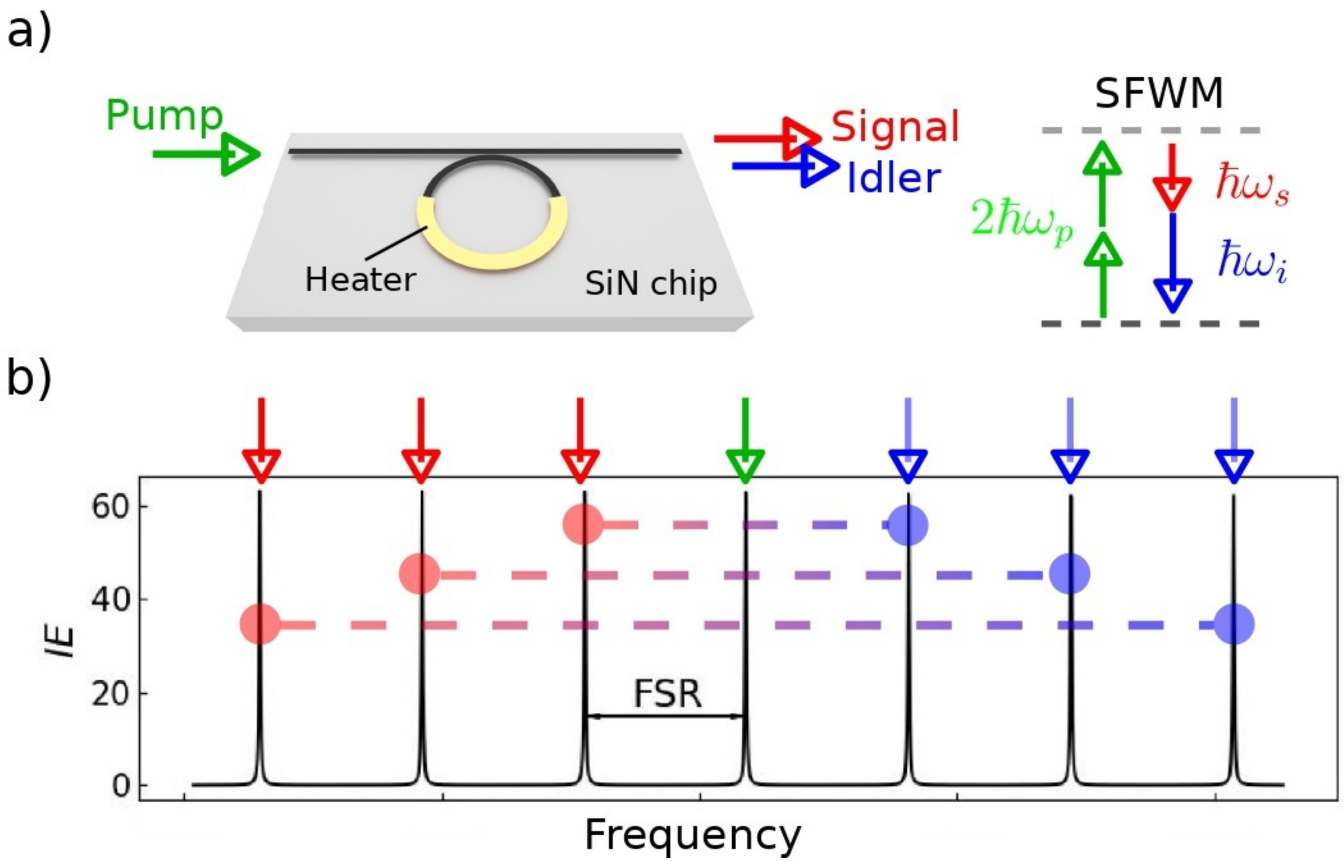


H. H. Lu et al., Phys. Rev. Lett. 125.12 (2020)

- High-dimensional entanglement
- Gate parallelization in a single spatial mode
- Inherent resilience to bit-flip errors
- Compatibility with WDM infrastructure
- Manipulation with fiber optic components

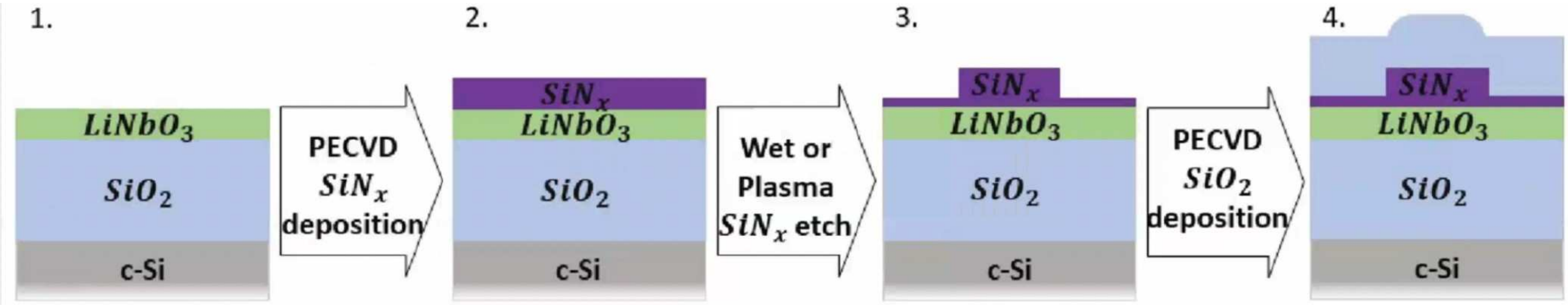
Waveguide technology

Ring resonator: one source generates many frequency bins



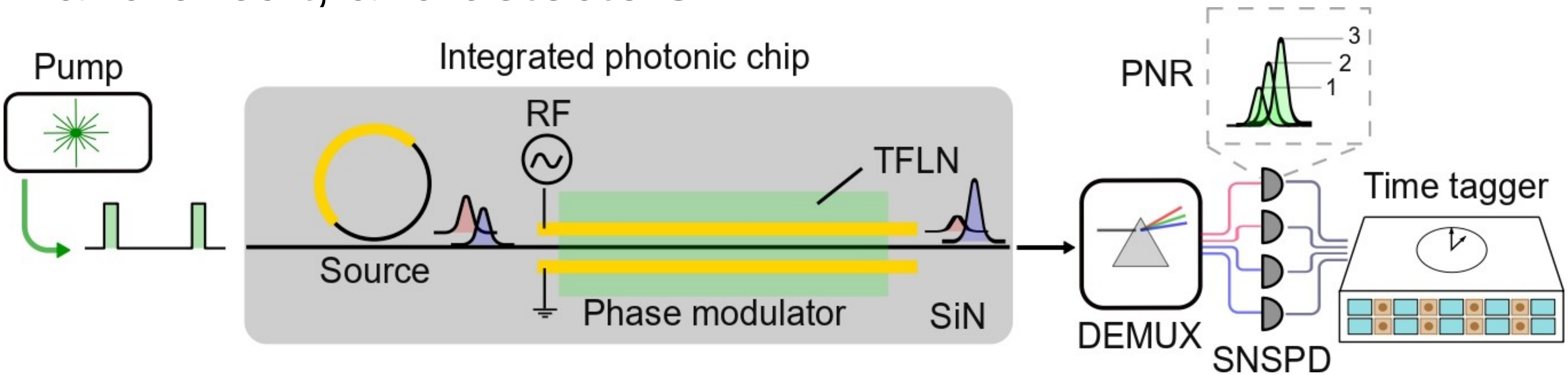
Waveguide technolgy

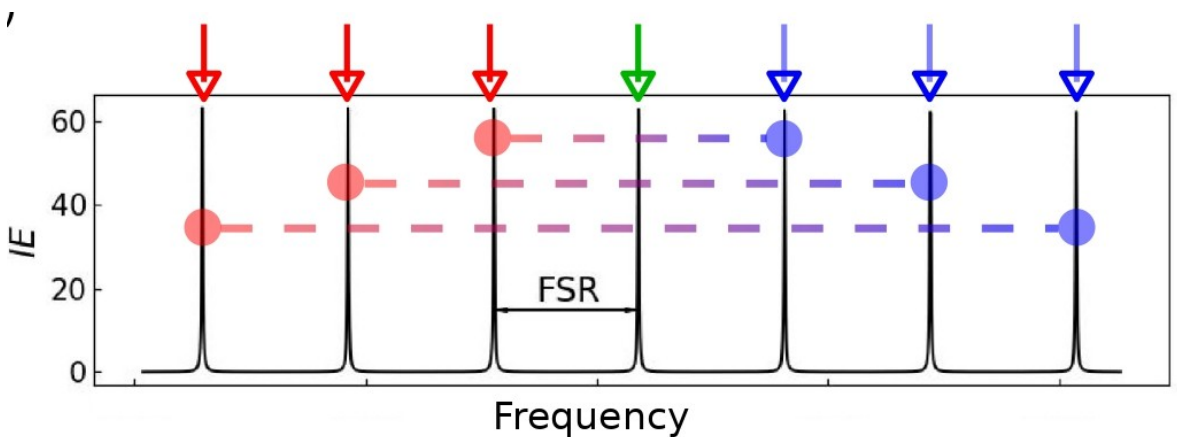
1) Strip loaded configuration
2) Synergy with UNIDET
3) For this experiment we need photon number resonving detectors
4) Devices purchased from Ligentech



Scheme of the experiment

1. We can couple frequency modes with a phase modulator;
2. Compact set up that can access many frequency modes;
3. Potential for a fully integrated platform, source modulator and circuit, and detectors.

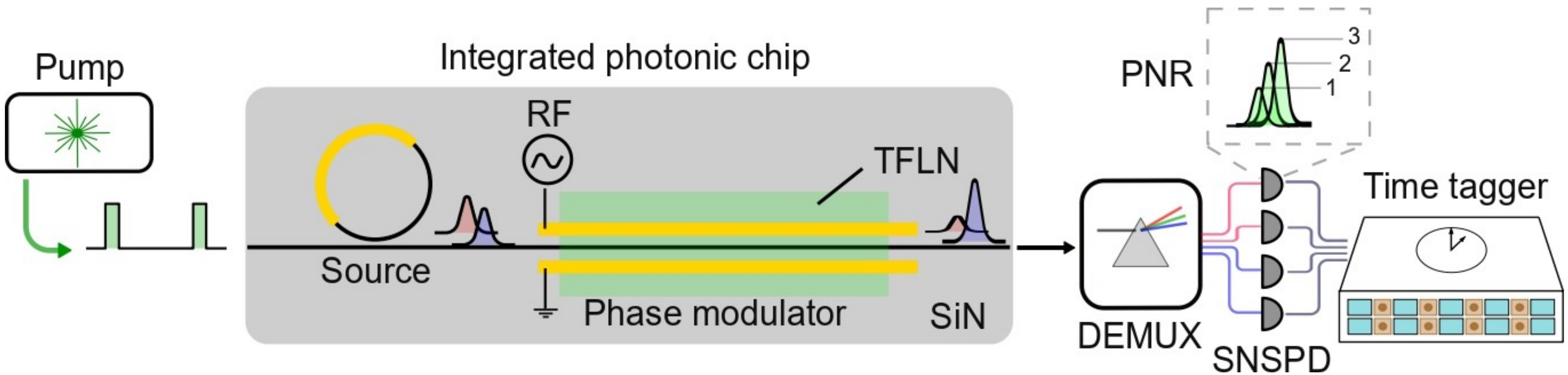




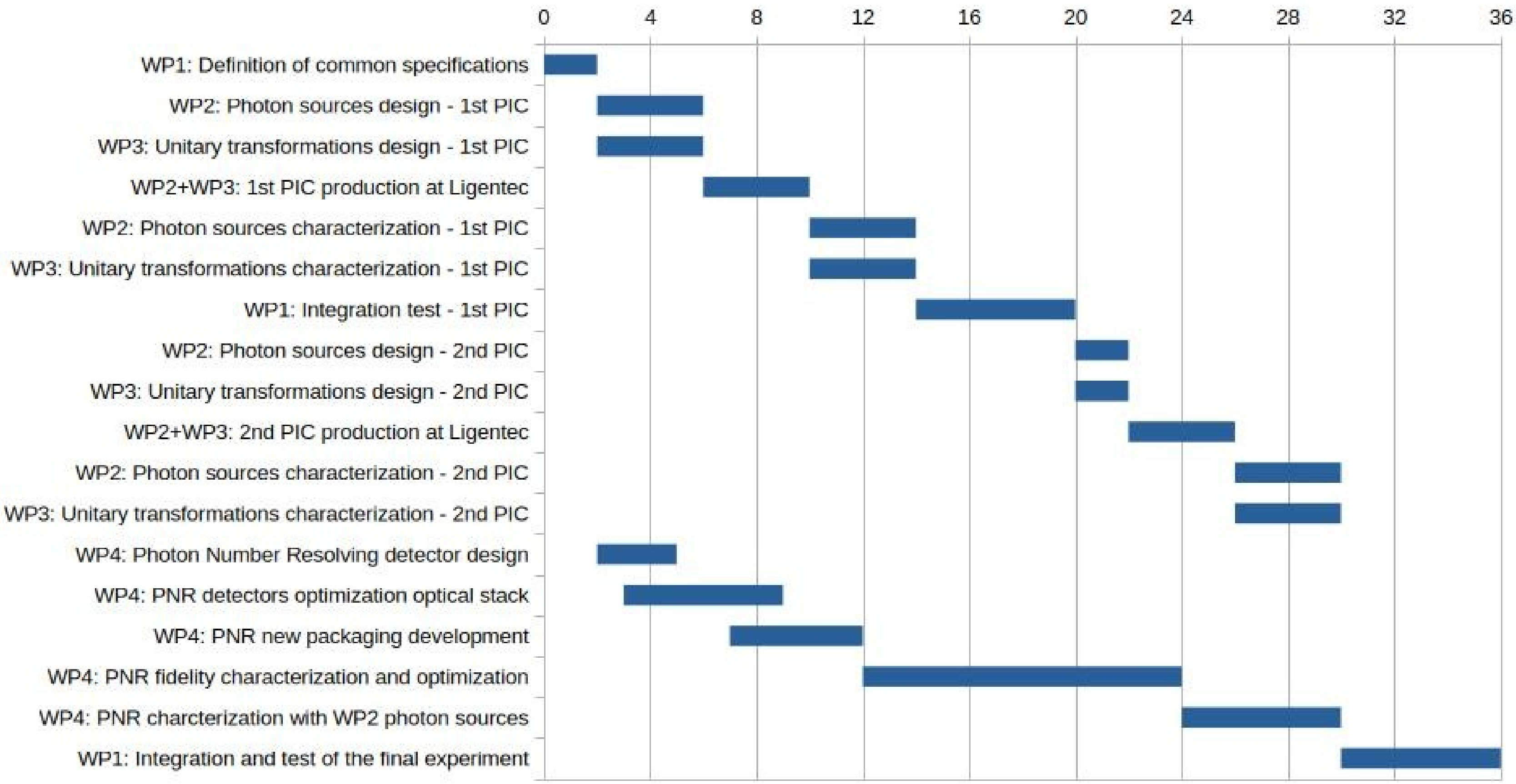
Main goal: demonstration of a non universal quantum processor

The experimental results of boson sampling allow to calculate the permanent of the unitary matrix encoded in the optical network.
This problem can be mapped into:

1. graph similarity problem, a fundamental problem in several fields like drug discovery
2. social network analysis
3. computer vision



Gantt chart


0
4
8
12
16
20
24
28
32
36
WP1: Definition of common specifications
WP2: Photon sources design - 1st PIC
WP3: Unitary transformations design - 1st PIC
WP2+WP3: 1st PIC production at Ligentec
WP2: Photon sources characterization - 1st PIC
WP3: Unitary transformations characterization - 1st PIC
WP1: Integration test - 1st PIC
WP2: Photon sources design - 2nd PIC
WP3: Unitary transformations design - 2nd PIC
WP2+WP3: 2nd PIC production at Ligentec
WP2: Photon sources characterization - 2nd PIC
WP3: Unitary transformations characterization - 2nd PIC
WP4: Photon Number Resolving detector design
WP4: PNR detectors optimization optical stack
WP4: PNR new packaging development
WP4: PNR fidelity characterization and optimization
WP4: PNR charcterization with WP2 photon sources
WP1: Integration and test of the final experiment

Budget for 2026-2028

Unit	Item	2026	2027	2028	Description
PV	Travel	2	2	2	Collaboration and common tests
	Cons		63		Si3N4 + LiNbO3 PIC production at Ligentec
	Cons	5	5	5	Laboratory consumables
RM2	Travel	2	2	2	Collaboration and common tests
	Cons	63			Si3N4 + LiNbO3 PIC production at Ligentec
	Cons	7	7	7	Cleanroom consumables at CNR-IFN
	Cons	5	5	5	Laboratory consumables
	Equip	12			RF tone generator (contribution)
TIFPA	Travel	2	2	2	Collaboration and common tests
	Cons	5	5	5	Laboratory consumables
TOTAL		103	91	28	
TOTAL				222	