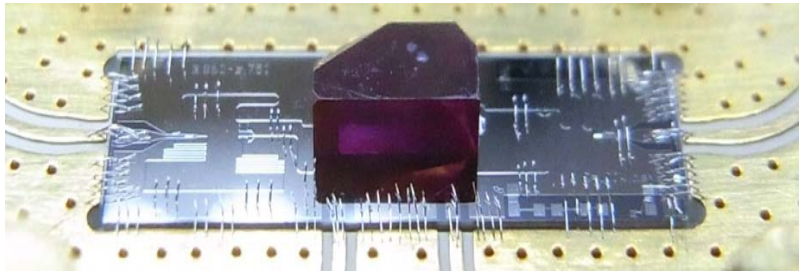
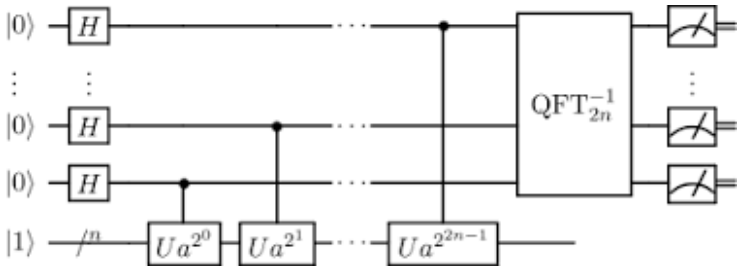
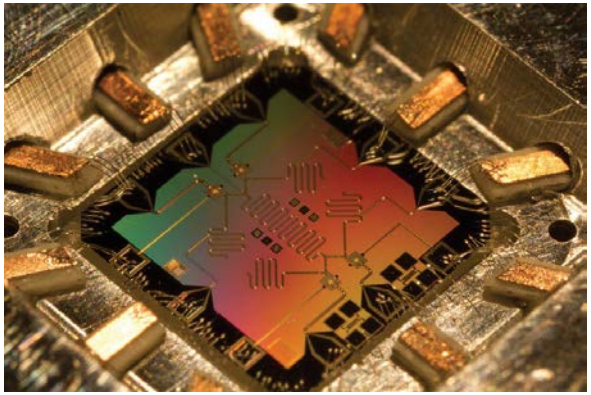
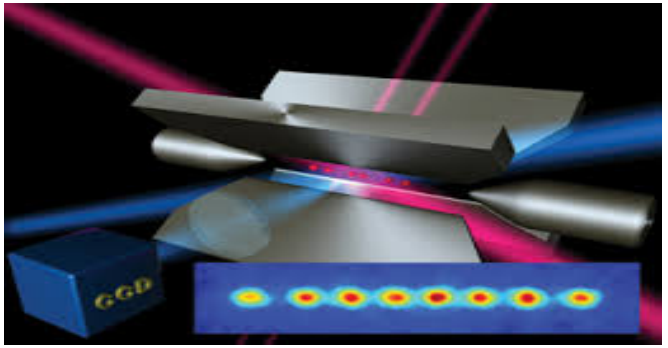




Quantum Computing axis





Quantum computing axis : the board

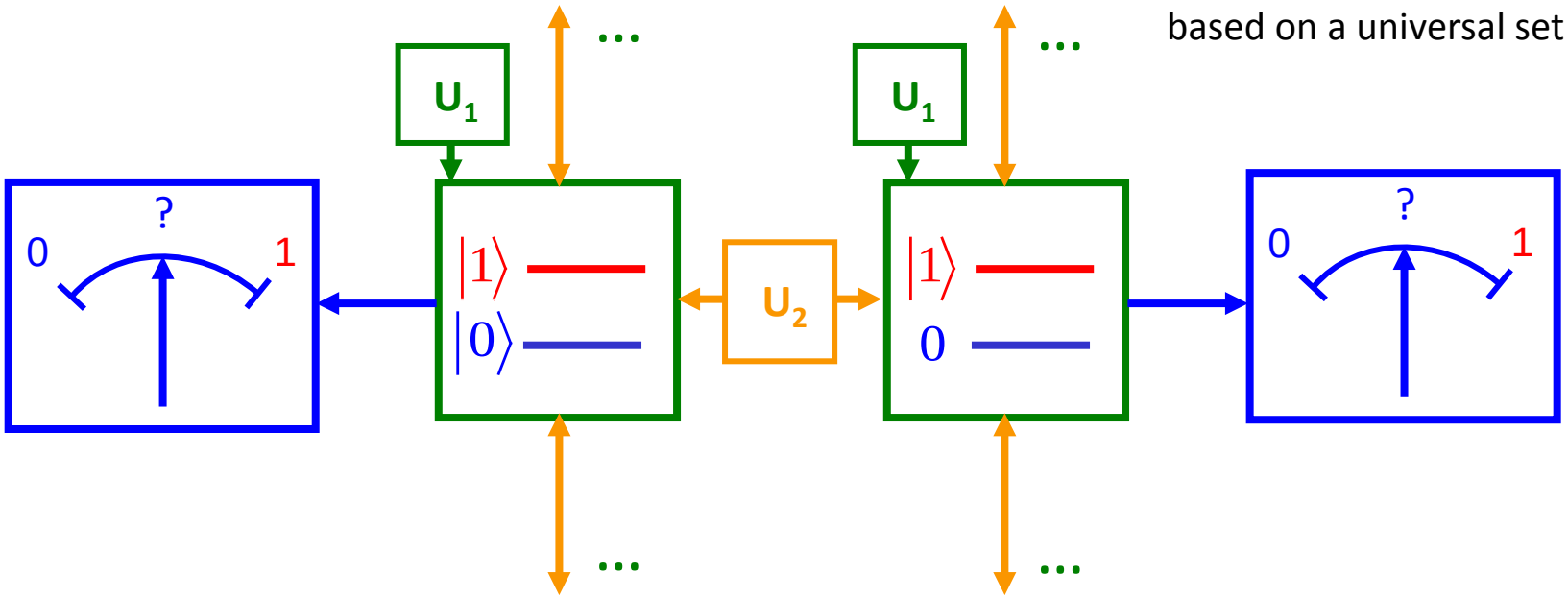
www.sirteq.org

Patrice Bertet	**Service de Physique de l'Etat Condensé CEA/CNRS**
Iordanis Kerenidis	**Institut de Recherche en Informatique Fondamentale CNRS/Université Paris-Diderot**
Michel Brune	Laboratoire Kastler-Brossel CNRS/Ecole Normale Supérieure/Université Pierre-et-Marie-Curie
Loïc Lanco	Centre de Nanosciences et de Nanotechnologie CNRS
Jean-Pierre Tillich	Equipe SECRET INRIA

24 groups , half experimental half theoretical

Quantum computing in a (small) nutshell

A quantum Turing machine
based on a universal set of gates



- qubit: 2-level-system $|\psi\rangle = a|0\rangle + b|1\rangle$ resetable to $|0\rangle$
- A few single qubit gates $U_1|\psi\rangle$
- a 2-qubit entangling gate $U_2|\alpha_0,\alpha_1,\alpha_2,\alpha_3\rangle_{00,01,10,11}$

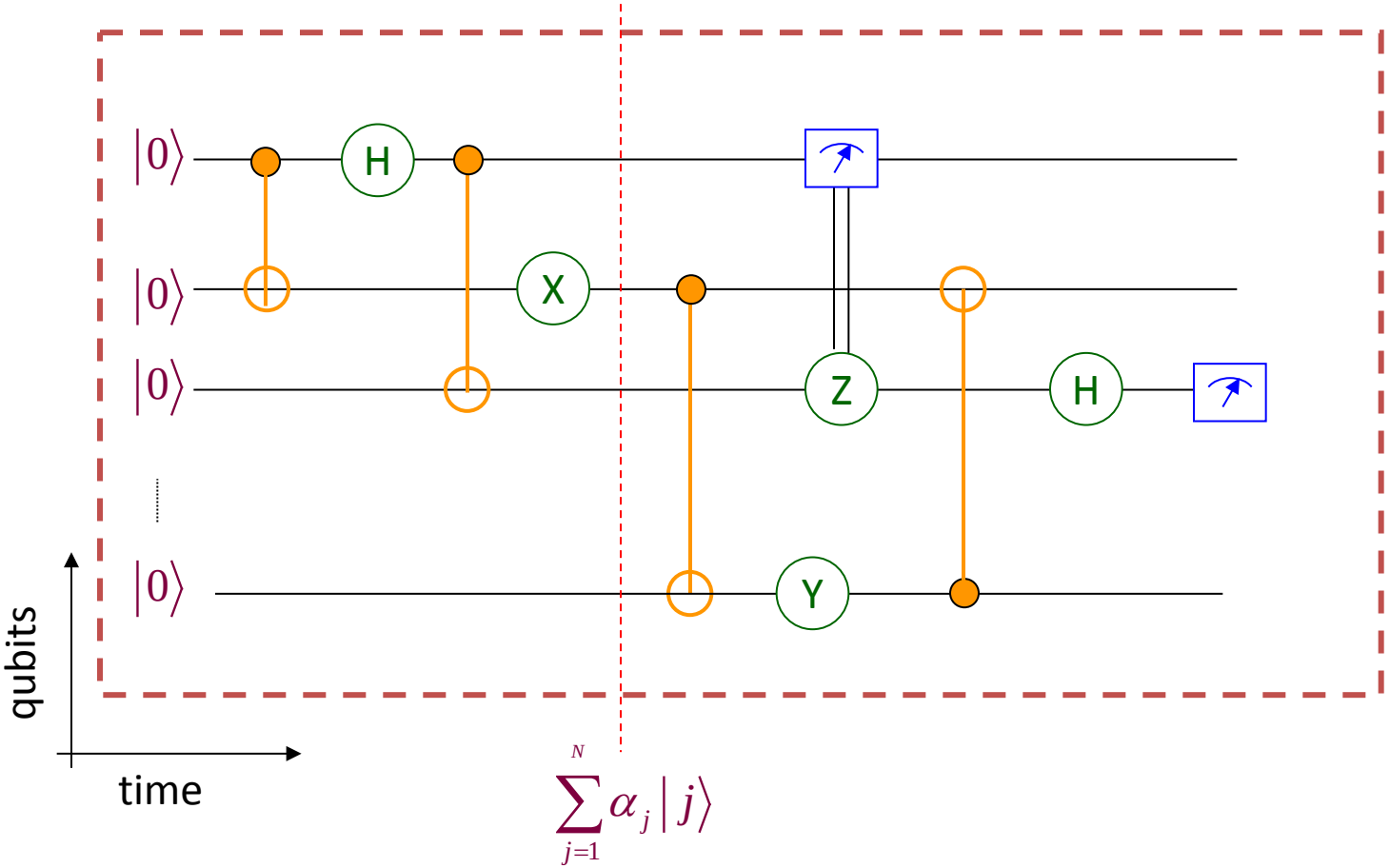
} universal set

- qubit readout with high fidelity

Quantum computing in a (small) nutshell

n qubits ⇒ N = 2^n basis states $\overbrace{|010001\ldots1\rangle}^{n} = |p\rangle$

Universal reversible single- and two-qubit gates arranged sequentially.

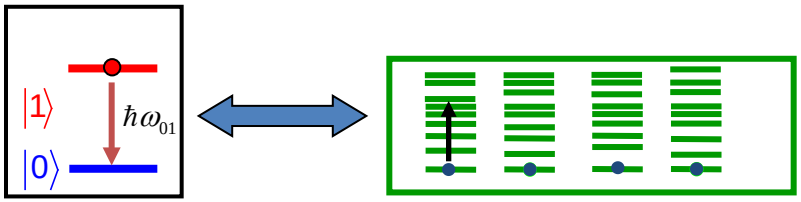


Quantum computing major obstacle: decoherence

registre $|\psi\rangle = \alpha_0 |0,0,\ldots,0\rangle + \alpha_1 |1,0,\ldots,0\rangle + \ldots + \alpha_{2^n-1} |1,1,\ldots,1\rangle$

Relaxation (spontaneous emission)

qubit j — environnement

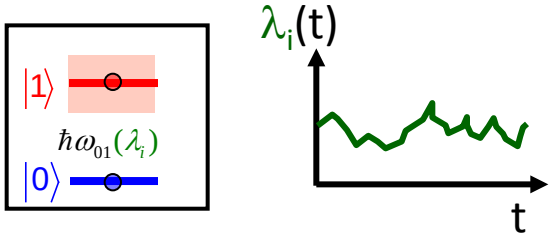


$|1\rangle_j$

$T_1^{-1} = \Gamma_1$

Pure dephasing

low-frequency noise



$a|0\rangle_j + be^{i\varphi(t)}|1\rangle_j$

low-frequency noise

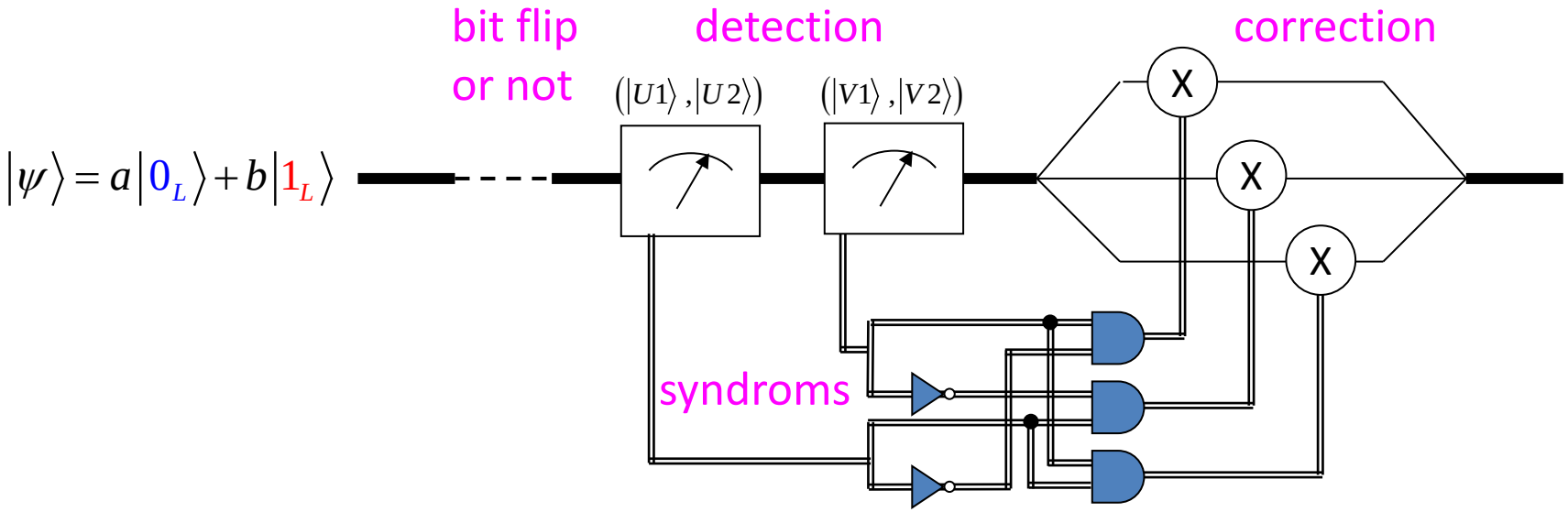
Γ_φ

$\left\langle e^{i\varphi(t)} \right\rangle \approx e^{-\Gamma_2 t}$

$T_2^{-1} = \Gamma_2 = \Gamma_\varphi + \frac{\Gamma_1}{2}$

Use redundancy (despite non-cloning)

Example: relaxation (bit-flip) correction $\left(|0_L\rangle, |1_L\rangle\right) = \left(|000\rangle, |111\rangle\right)$



Works if error/gate < certain threshold.

For « surface code » , threshold < 1%

Quantum computing : algorithms

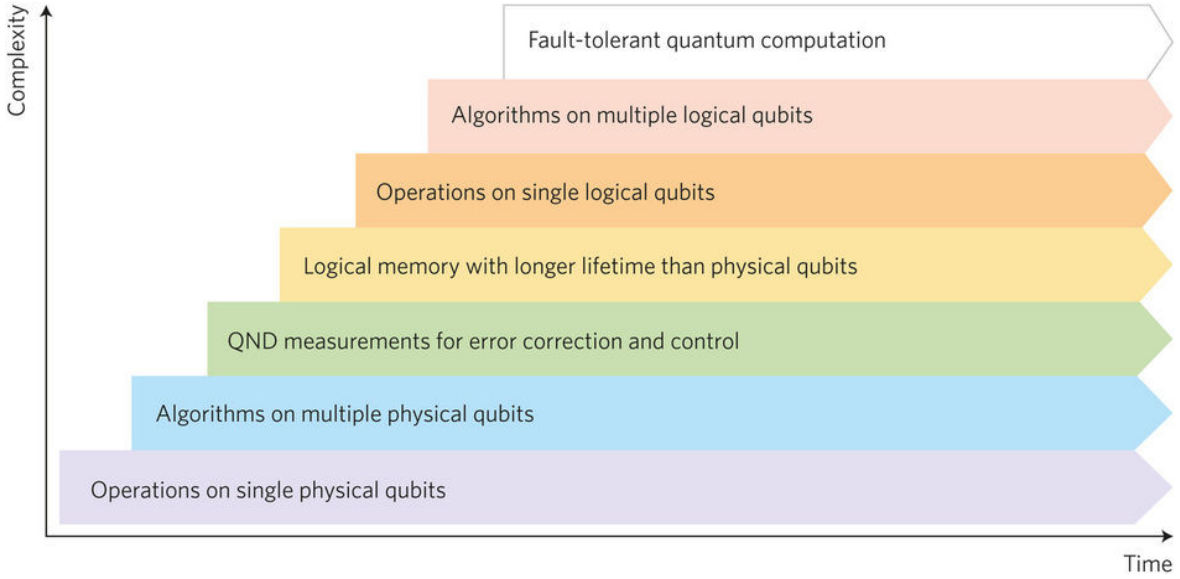
What could be done with a quantum computer ?

- Search and optimization problems (Grover, …)
- Factorization of large numbers (Shor)
- Find the energy spectrum of molecules

Big industrial investments ongoing

Quantum computing : outstanding challenges

www.sirteq.org



R. Schoelkopf & M. Devoret, Nature (2013)

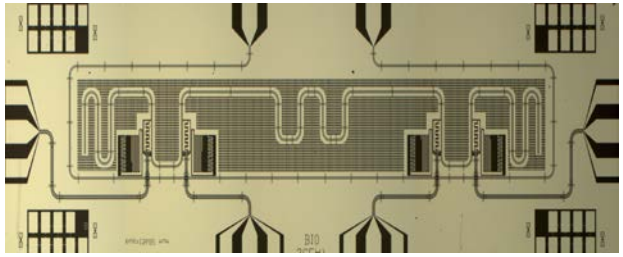
Experimental

- Improve coherence time of existing qubits
- Find best physical platform
- Improve the accuracy of gates and qubit readout

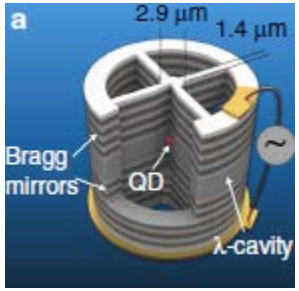
Theoretical (see talk by E. Kashefi)

- Improve/Find new Quantum Error Correcting codes (less overhead needed)
- Explore Quantum Error Correction under more realistic noise models
- Explore « small-scale » implementations with realistic numbers of qubits, of gates, and of qubit control accuracy
- Find new algorithms

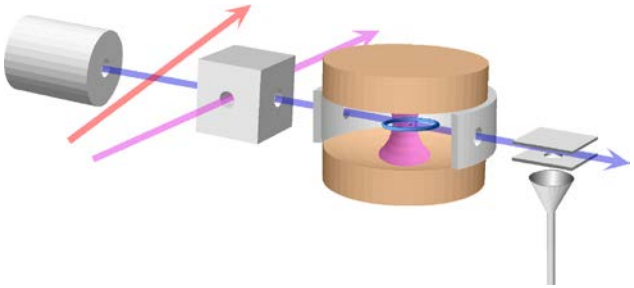
Physical platforms within SIRTEQ



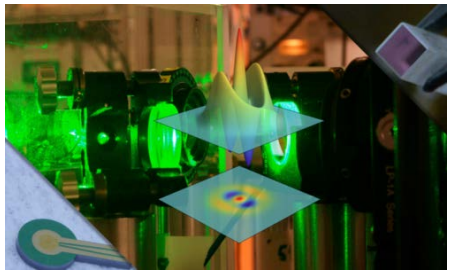
Superconducting circuits



Semiconducting quantum dots in a microcavity



Rydberg atoms coupled to microwave cavity

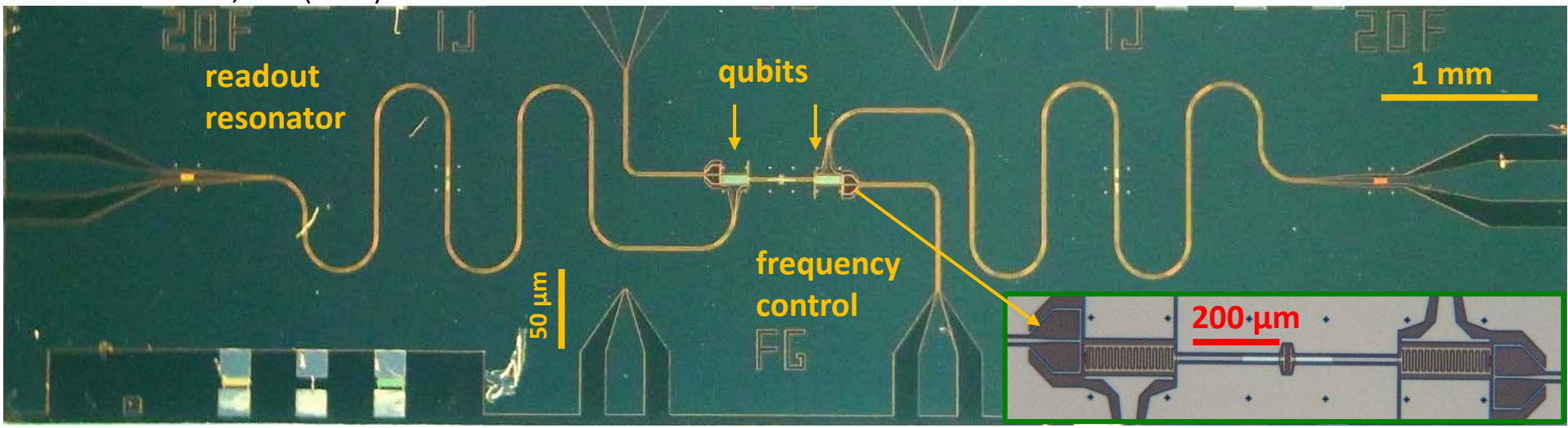


Photonic quantum states

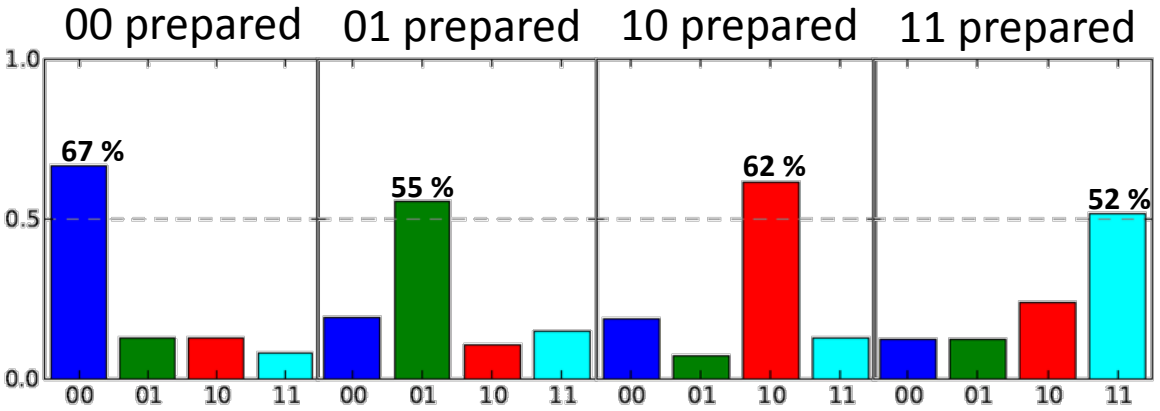
Highlights (1) : Grover's algorithm with superconducting qubits

A. Dewes et al., PRL (2011)
A. Dewes et al., PRB (2011)

Quantronics group, SPEC, CEA Saclay



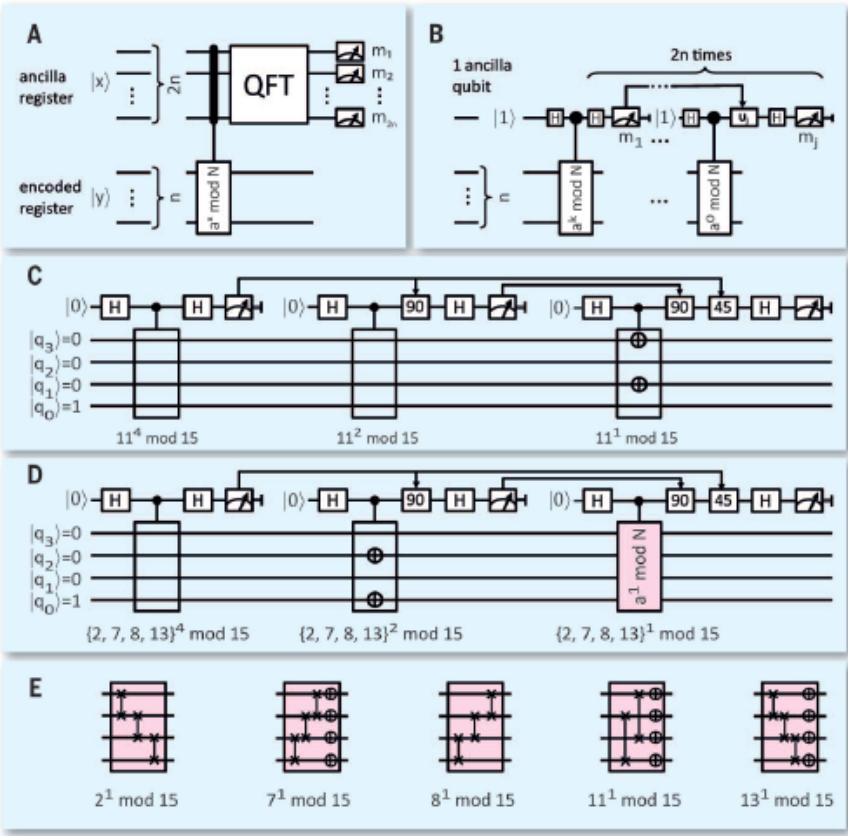
Two-transmon processor
+ quantum speedup in Grover search algorithm

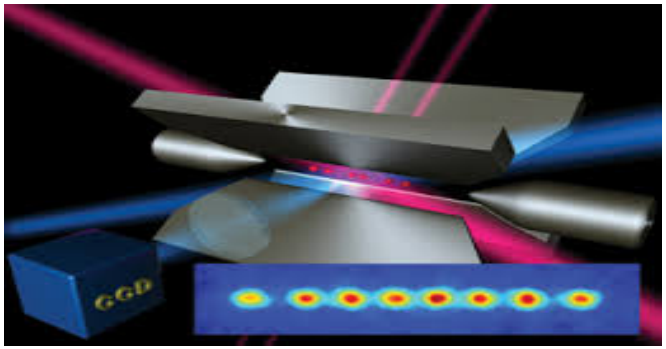


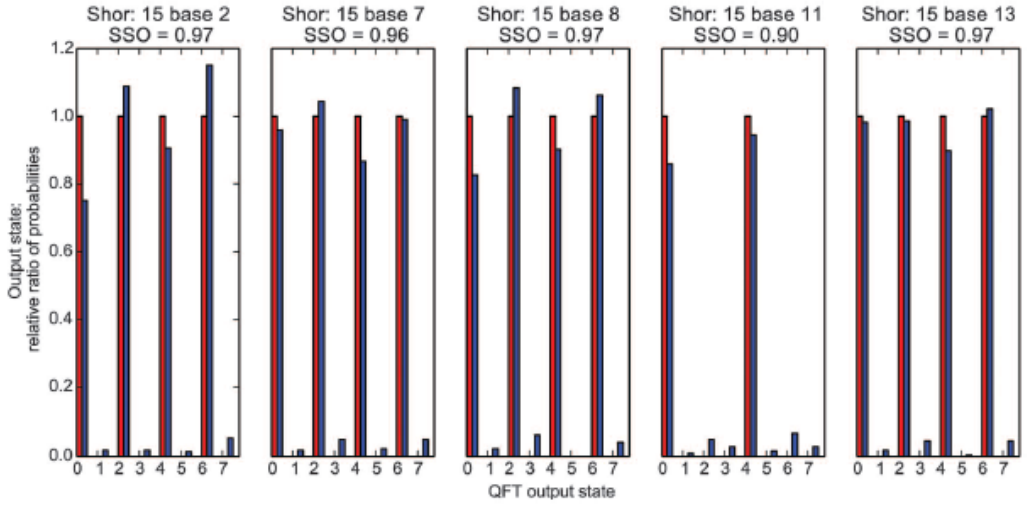
In one run of the experiment, the success rate is larger than the largest possible classical success rate of 50% : ***QUANTUM SPEEDUP***

Highlights (2) : Shor's algorithm with trapped ions

T. Monz et al., Science 2016 (R. Blatt's group)







Correct factoring of 15 with 99% probability

Conclusion

- Despite recent advances, remain major experimental and theoretical challenges to tackle before interesting problems can be treated by quantum processors, with or without Quantum Error Correction

- SIRTEQ will provide strong incentive to join experimental and theoretical efforts, which are key to future breakthroughs