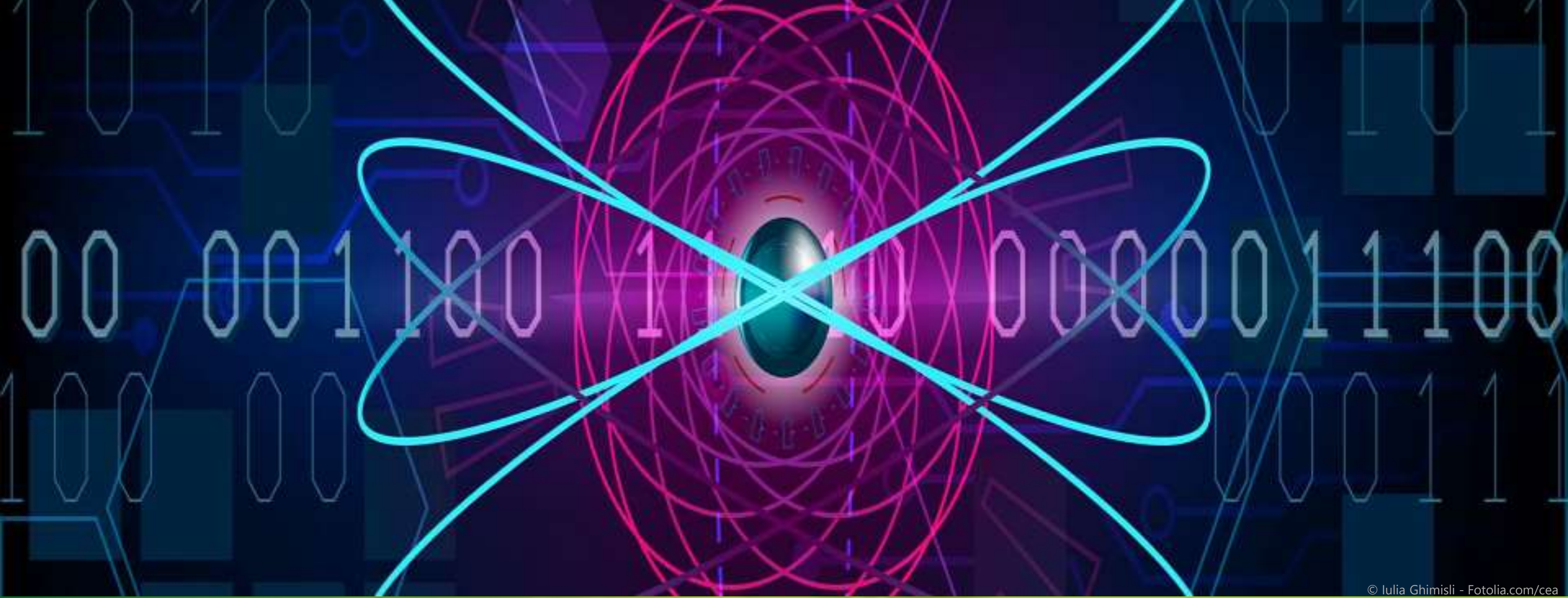


SILICON BASED QUANTUM COMPUTING

leti cea tech · irig · QuantumSilicon Grenoble · Université Grenoble Alpes · Institut Néel


BRAVE!

Quantum Silicon
Grenoble

European Research Council
Established by the European Commission

Physics

Quantum eng.

Mathematics

Computer science

Technology

leti
cea tech

irig
INTERDISCIPLINARY RESEARCH INSTITUTE OF GRENOBLE

NÉEL institut

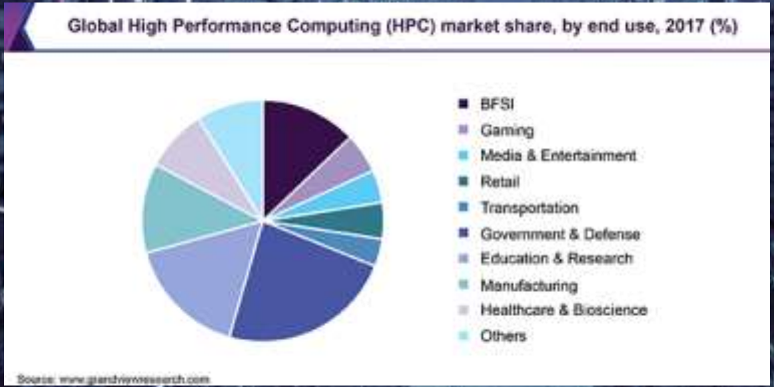
UNIVERSITÉ Grenoble Alpes

Quantum Engineering
Univ. Grenoble Alpes

Agenda

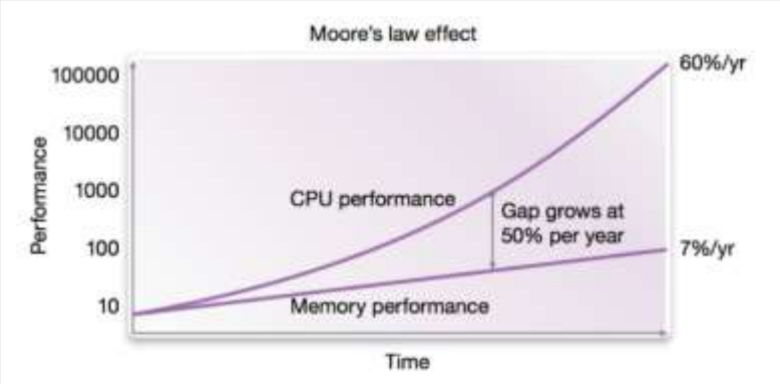
- Introduction
- Hardware status with focus on silicon
- How to go to large scale?
- ERC QuCube original idea
- Project organization
- Highlights and results

Opportunities
High performance computing



US$ 32 billions in 2017

Scaling limitations



Memory wall and power consumption

are in the way of growing computing capabilities

HOW TO REACH THE PROMISE OF QUANTUM COMPUTING?

QUANTUM SIMULATION

Better pharmaceutical, materials, chemistry, physics,…

MACHINE LEARNING & BIG DATA

Autonomous vehicles, finance, mathematics

CRYPTOGRAPHY

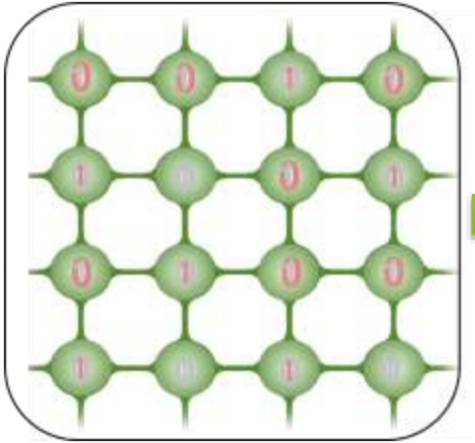
Security

Hundreds of qubits

Millions of errorless quantum operations

Millions of errorless quantum operations

Quantum Error
Correction protocols



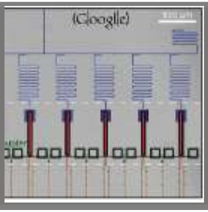
millions of physical qubits in a 2D array

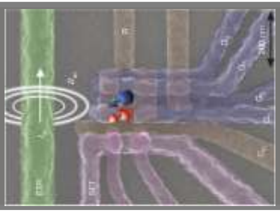
1 Errorless logical qubit
> 1000 physical qubits

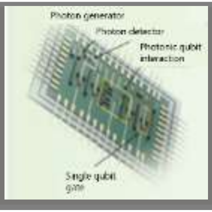
WHERE DOES QUANTUM COMPUTING STAND?

Hardware is at its infancy

Key platforms (Superconductor, Spin silicon, Ion trap, Photons)







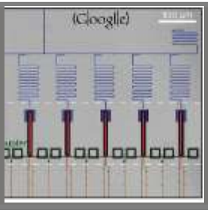
	Superconductor	Spin silicon	Ion trap	Photons
Entangled qubits	53	2	20	18

WHERE DOES QUANTUM COMPUTING STAND?

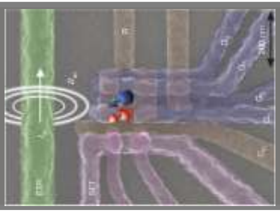
Hardware is at its infancy

Key platforms

Superconductor

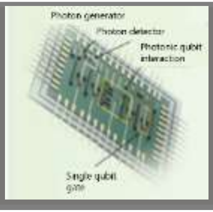


Spin silicon



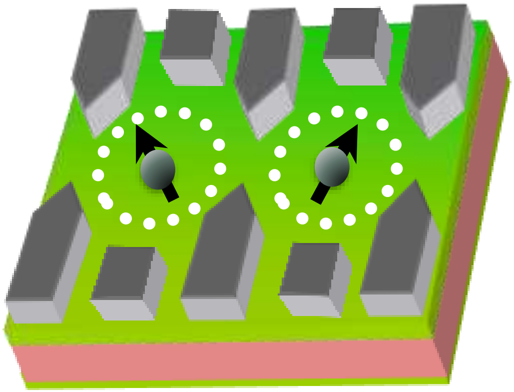
Ion trap

Photons



	Superconductor	Spin silicon	Ion trap	Photons
Entangled qubits	53	2	20	18
Size	(100µm)²	(100nm)²	(1mm)²	1 mm²
Fidelity	99.3%	98%	99.9%	50% (mesure) 98% (portes)
Speed	100 ns	5 µs	100 µs	1 ms
T° of operation	20mK	1K	Room T°	4K

Spin degree of freedom of an electron

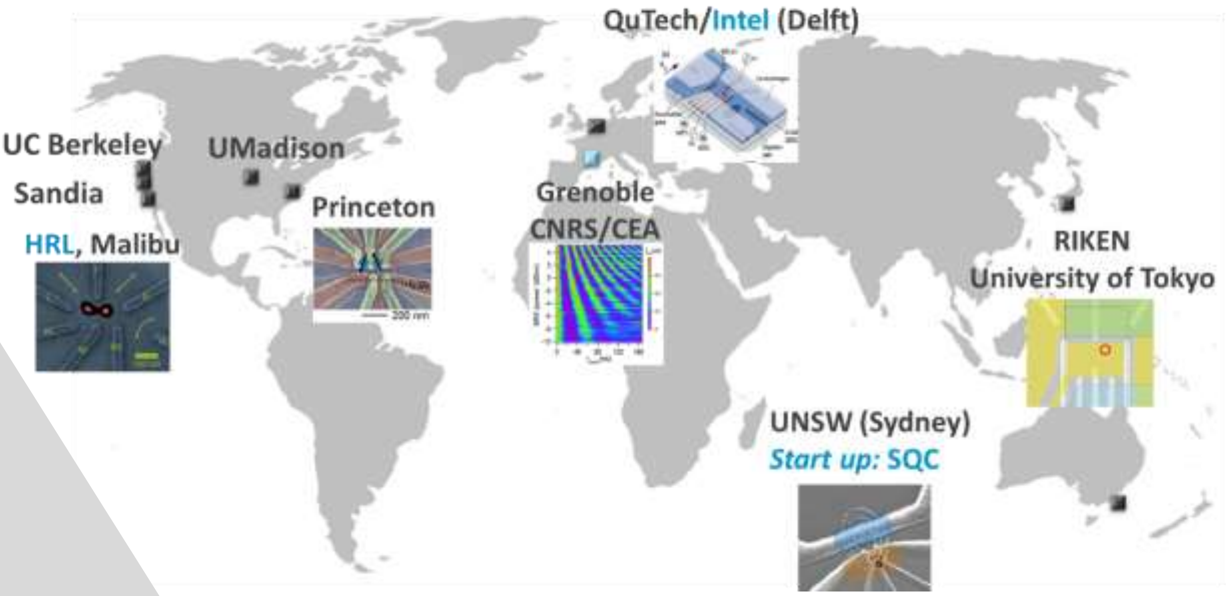


$0 \rightarrow |\uparrow\rangle$

$1 \rightarrow |\downarrow\rangle$

Gate defined quantum dots

Single and two qubits gate demonstrations

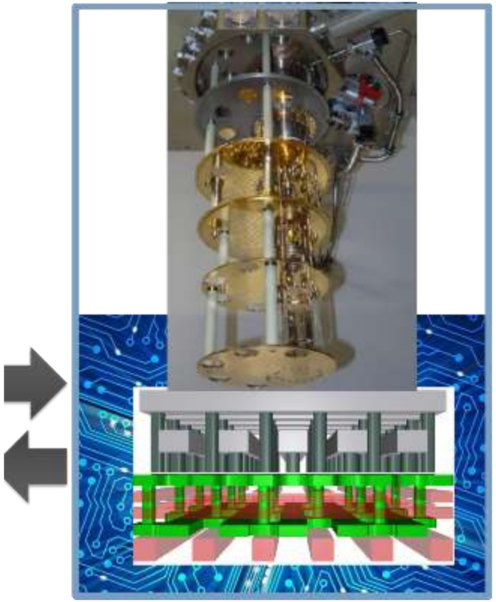


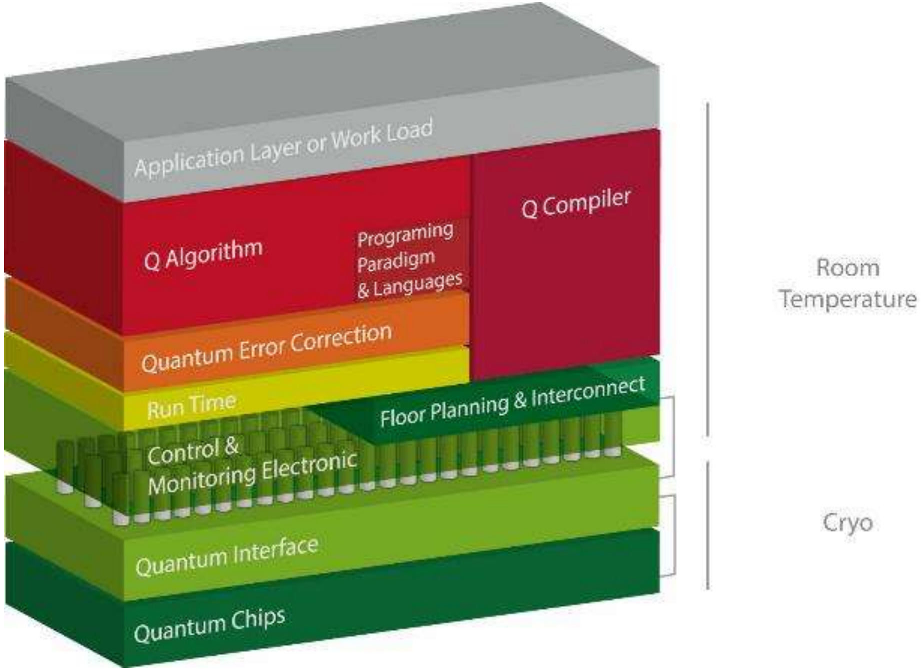
How to go to large scale?

- Variability
- Controlability
- Individual qubit addressing
- Cross talk
- Large scale coherence

OBJECTIVE

Design and fabricate a **quantum accelerator** encoding quantum information in silicon spins and develop low level software allowing its use to solve **dedicated** useful problems.

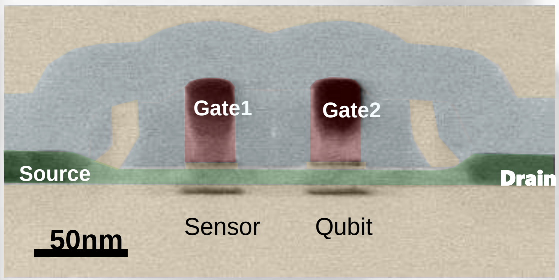


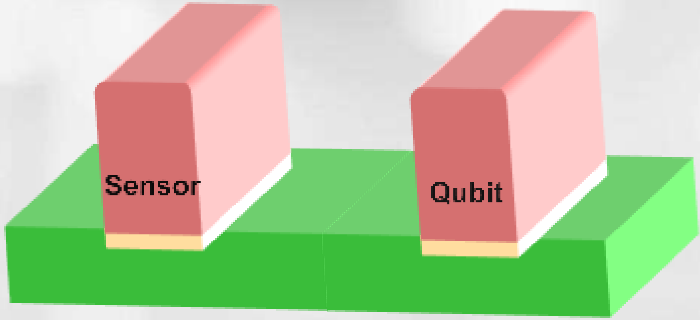


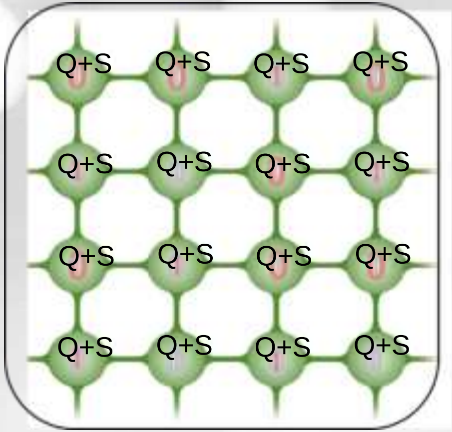
STRATEGY FOR BUILDING A QUANTUM COMPUTER

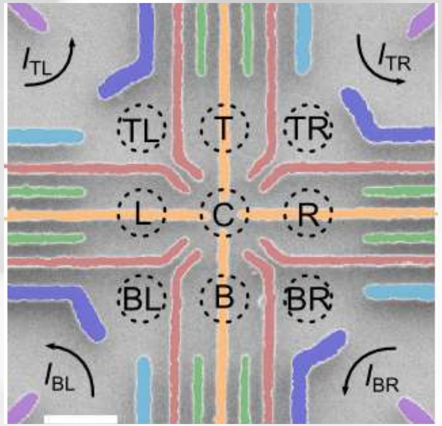
1. Definition of good quality single & few qubits
2. 2D array definition
3. Long distance quantum information transfer
4. Cryogenic large scale compatible architecture

Cryogenic large scale compatible architecture

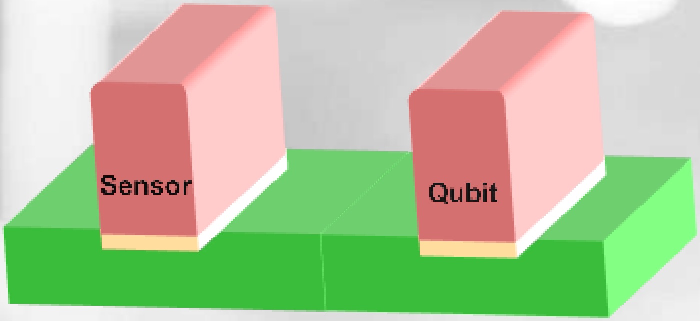




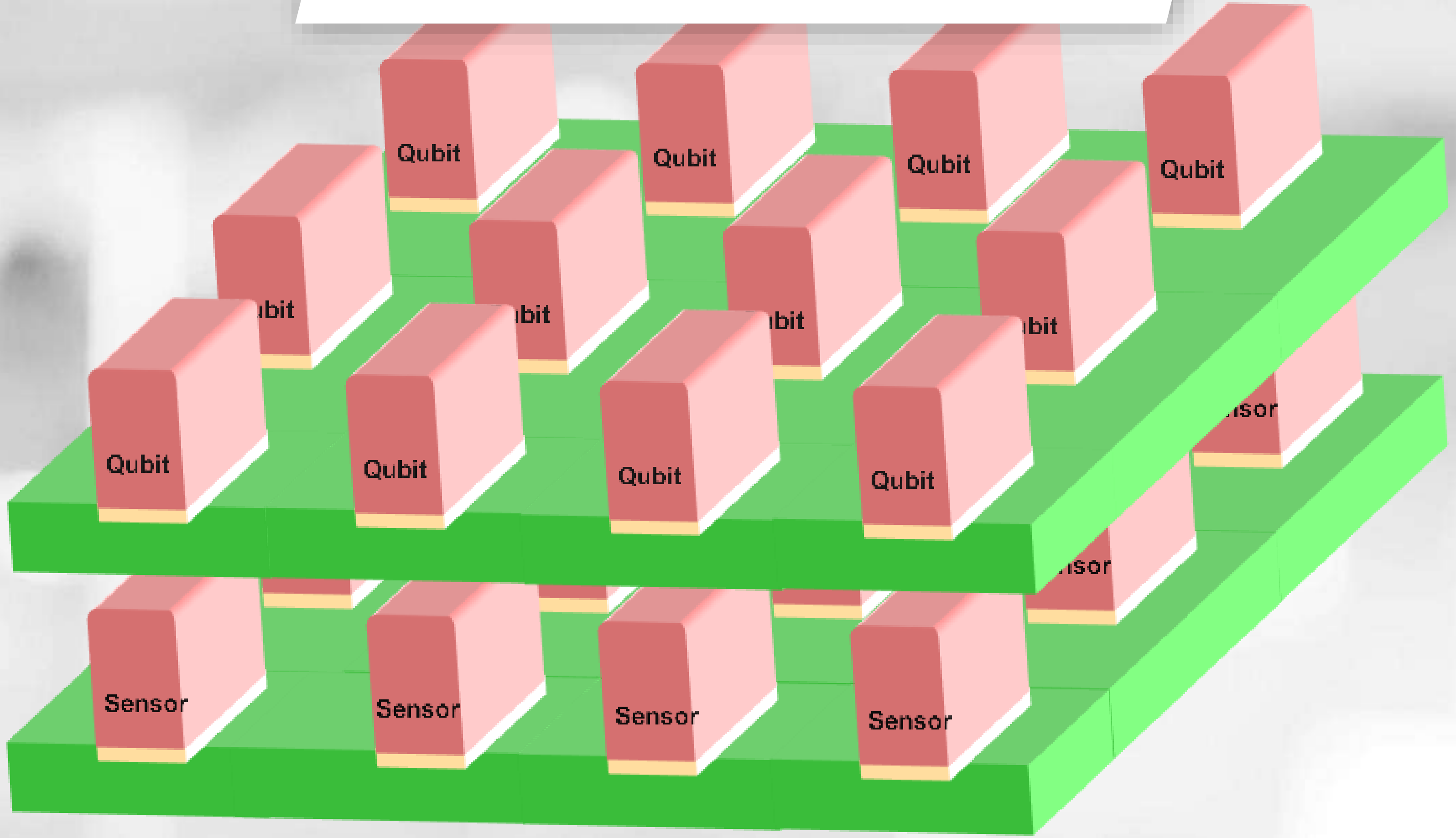




Cryogenic large scale compatible architecture

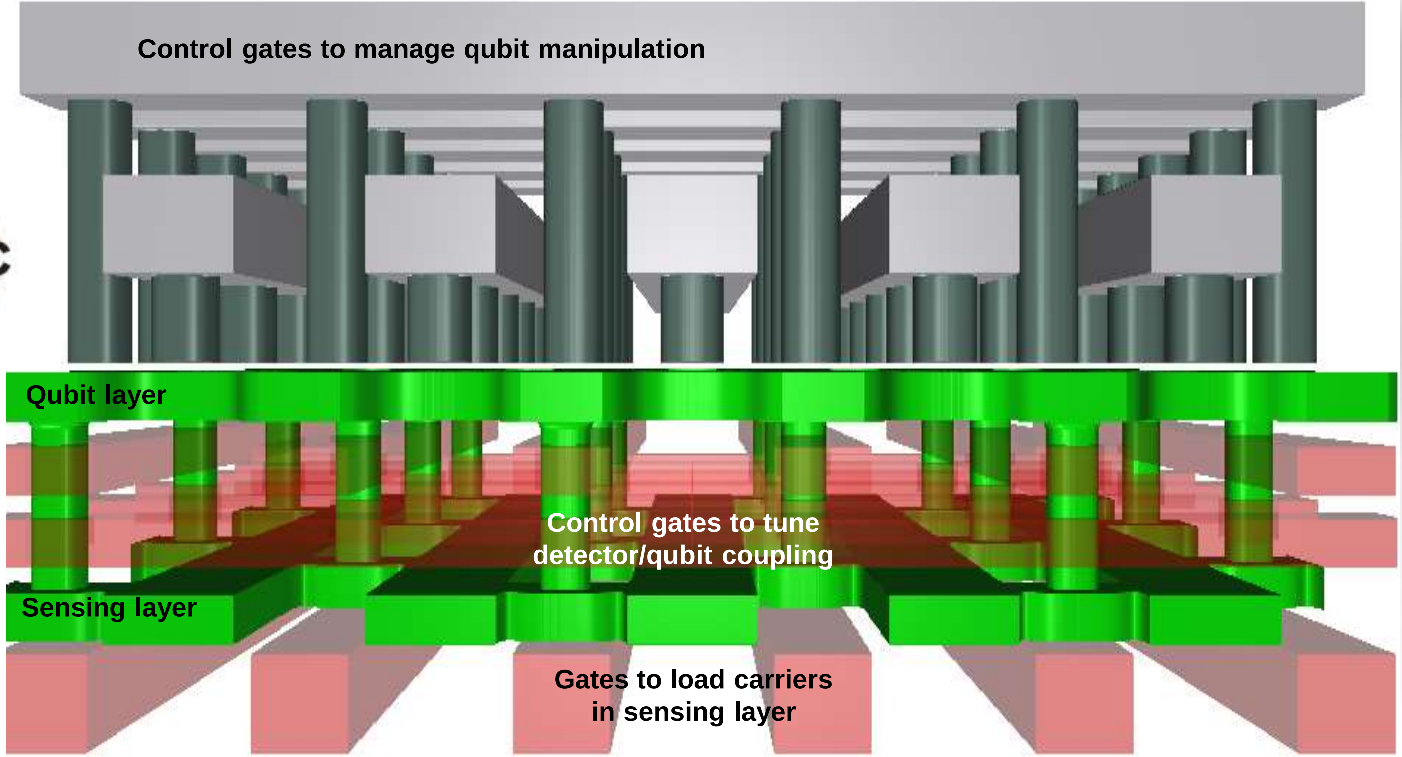


Cryogenic large scale compatible architecture

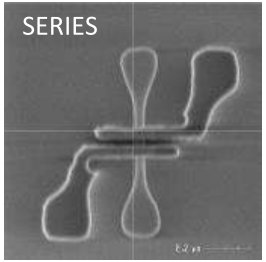


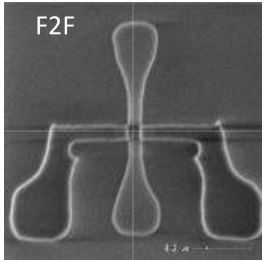
Cryogenic large scale compatible architecture

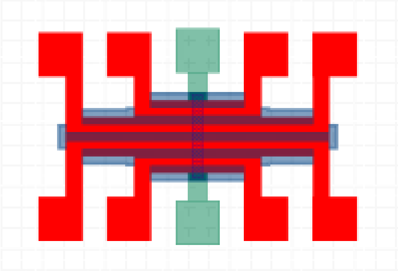
Meunier, De Franceschi, Vinet, Hutin (2017)

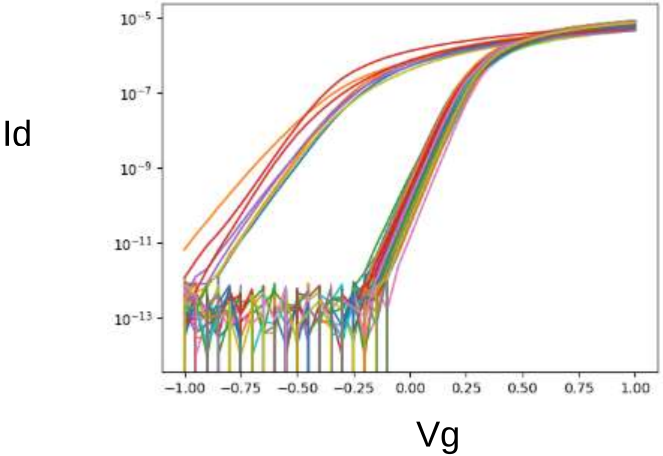


Fabrication highlights: robust baseline developments



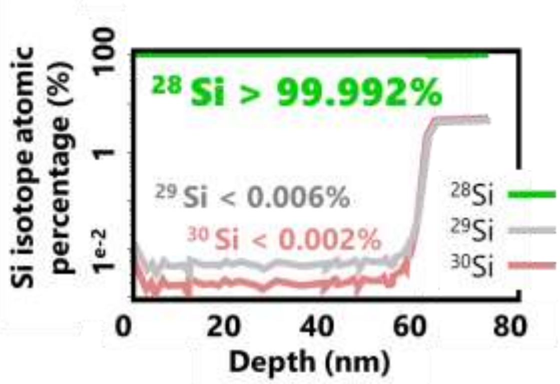






Fabrication highlights: materials optimization

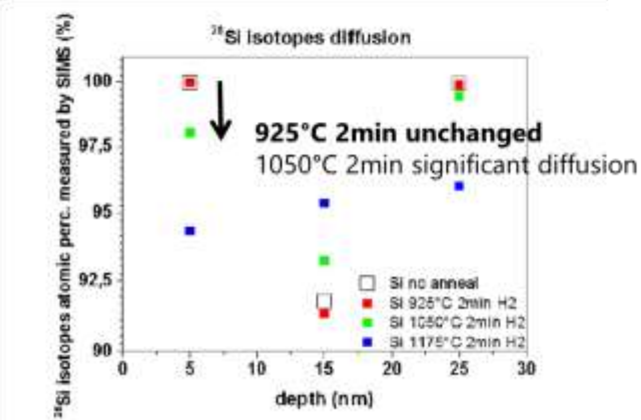
^{28}Si wafers



Mazzocchi et al., J of Crystal Growth (2018)

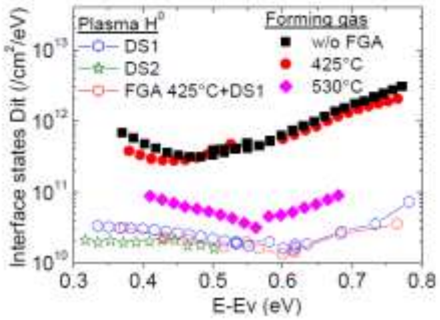
species	concentration (μmol/mol)
CH_4	≤ 0.05
C_2H_6	≤ 0.02
C_2H_4	≤ 0.02
C_3H_6	≤ 0.02
C_3H_8	≤ 0.01
i-C_4H_{10}	≤ 0.02
n-C_4H_{10}	≤ 0.02
More than 52 other species	$\leq 80.35 \pm 20.135$

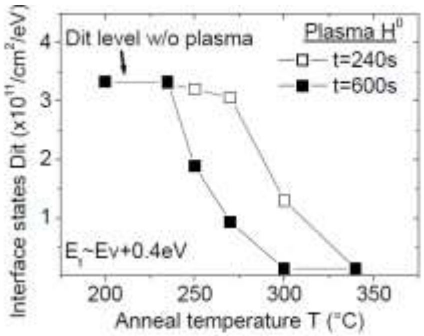
Microelectronics grade ^{28}Si



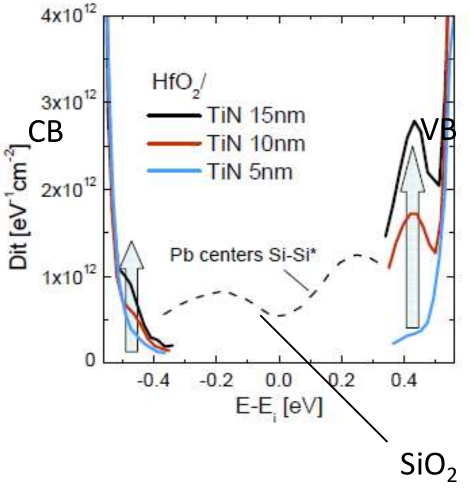
Measurement of 29Si self diffusion in 28Si

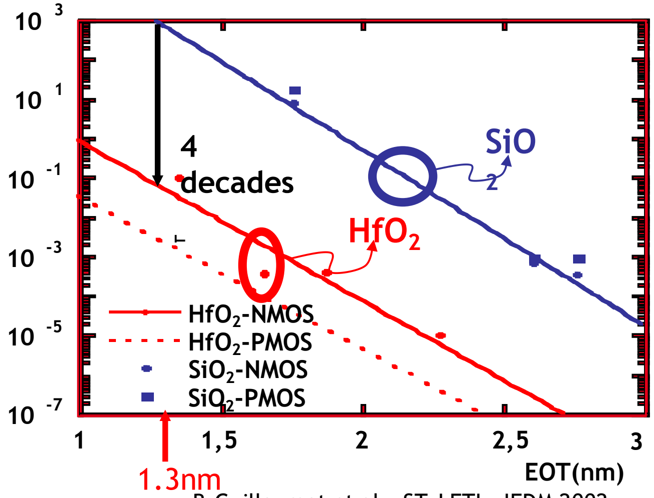
Fabrication highlights: materials optimization





X Garros, IRPS 2005



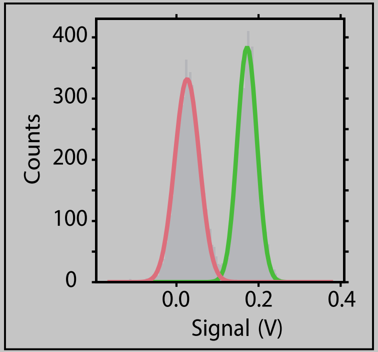


B.Guillaumot et al., ST, LETI, IEDM 2002

Good quality qubits

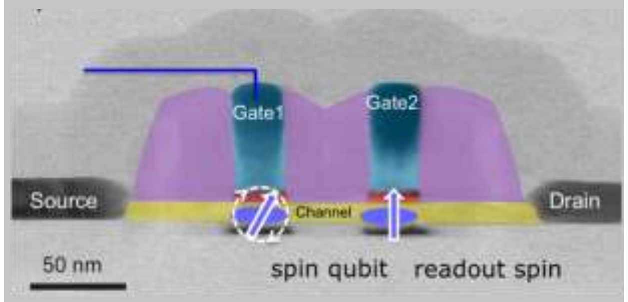
First CMOS spin qubits
2016

Maurand et al, Nature Comm 2016



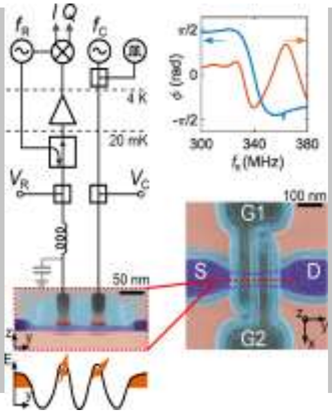
First one qubit with manipulation & scalable read out co-integrated
2019

Crippa et al, Nature Comm 2019



1 qubit read out
Fidelity > 98%
2019

Urdampilleta et al, Nature Nano 2019



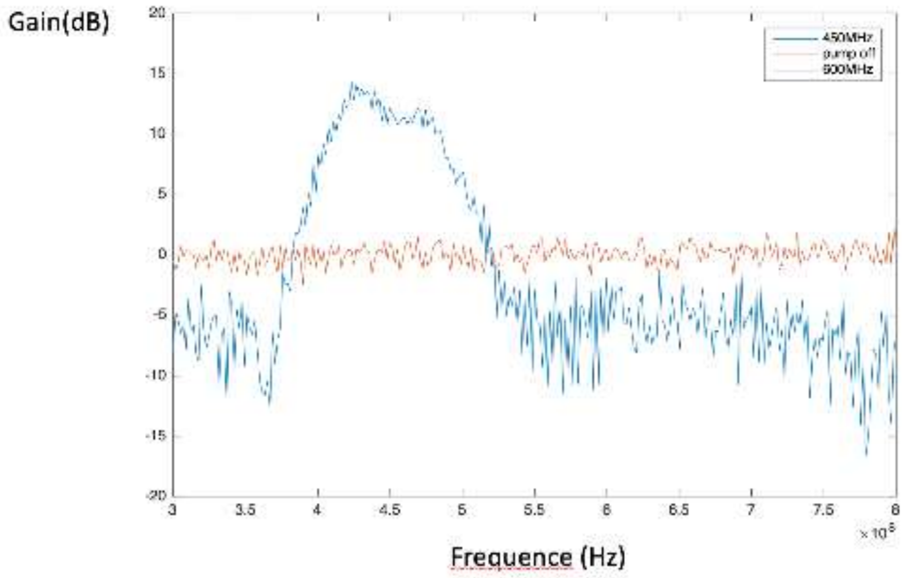
Good quality qubits highlights

Gate-reflectometry with superconducting TWPA to increase fidelity and read out speed

- Design and fabrication of TWPA (N. Roch's team)
- First 0.3 K

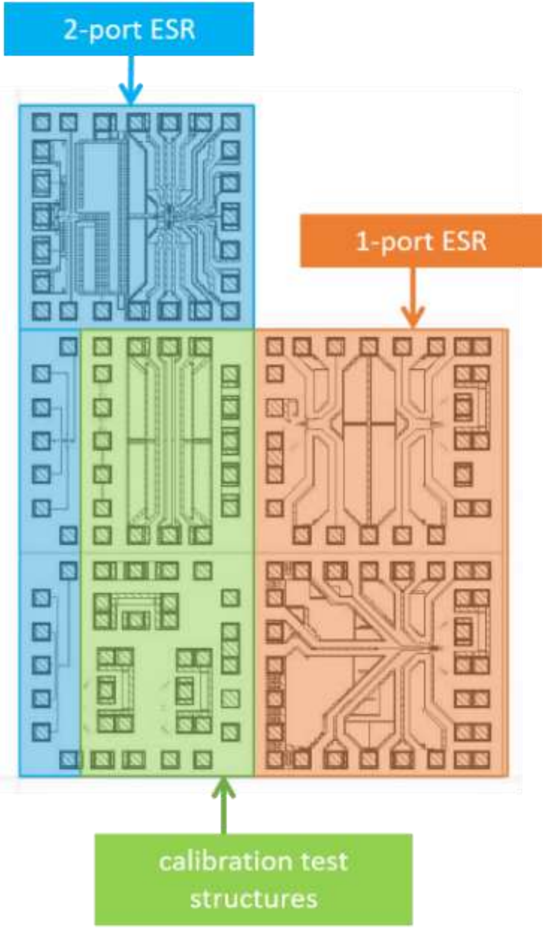
TWPA is functionning at low frequency
It is at the SoA

To go further new designs have been implemented



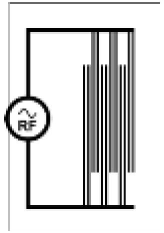
Good quality qubits highlights

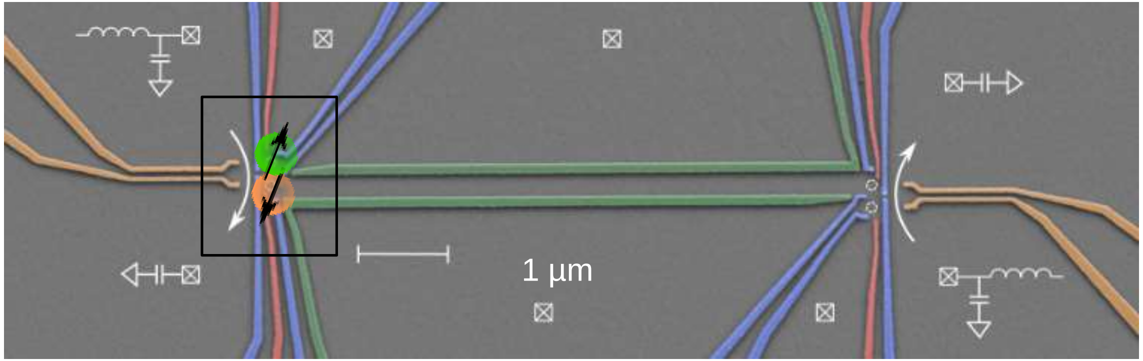
Design and integration of metal lines for ESR manipulation
(for electron spin qubits manipulation)

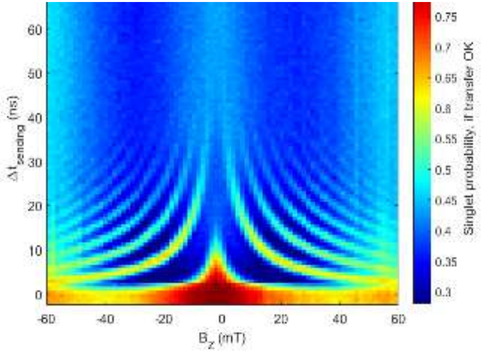


Towards large scale highlights
Fast spin coherent link and Spin entanglement at distance

Fast spin coherent link
and spin entanglement at distance

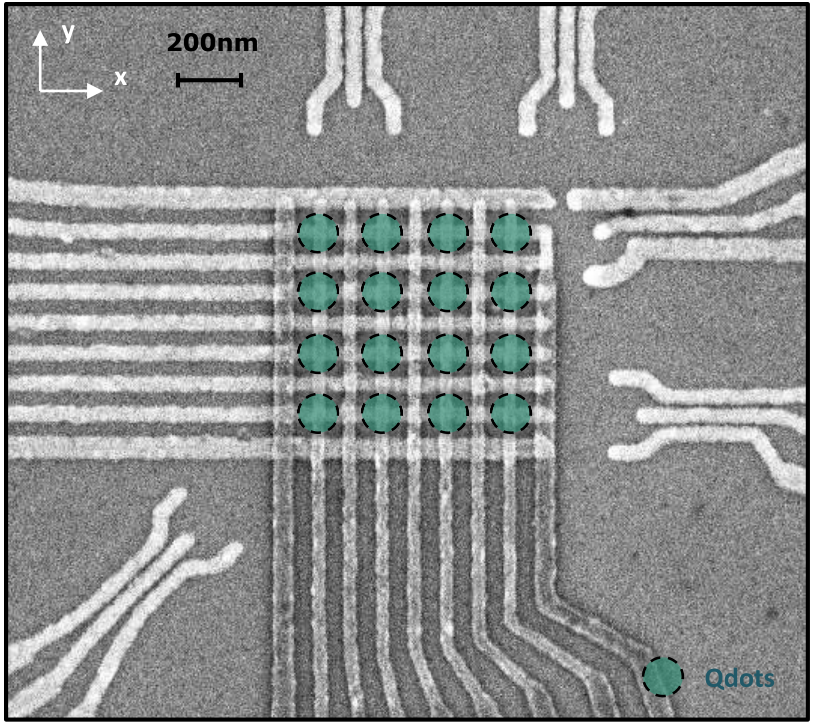






B. Jadot (Grenoble)
Unpublished 2018

Towards large scale highlights
4x4 line-column addressing

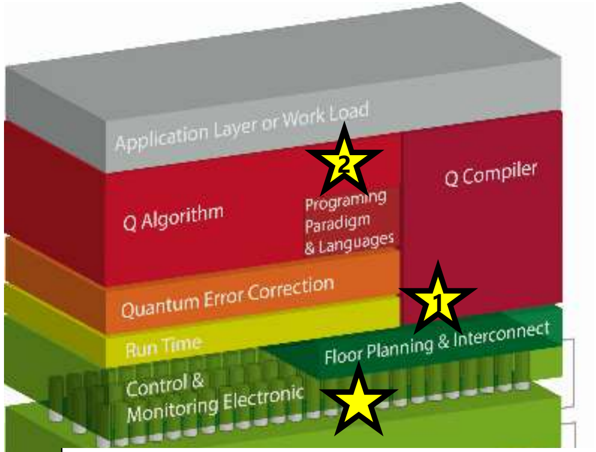


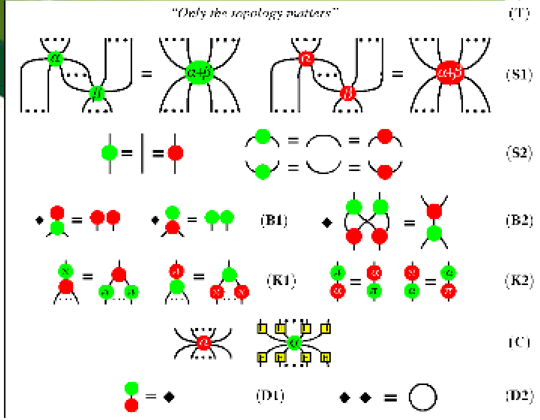
in III-V

Control electronics highlights

First co-integration of a quantum device quantum device (double quantum dot) together with control electronics in commercial technology (28FDSOI)
To be published @ ISSCC2020

Quantum algorithms highlights

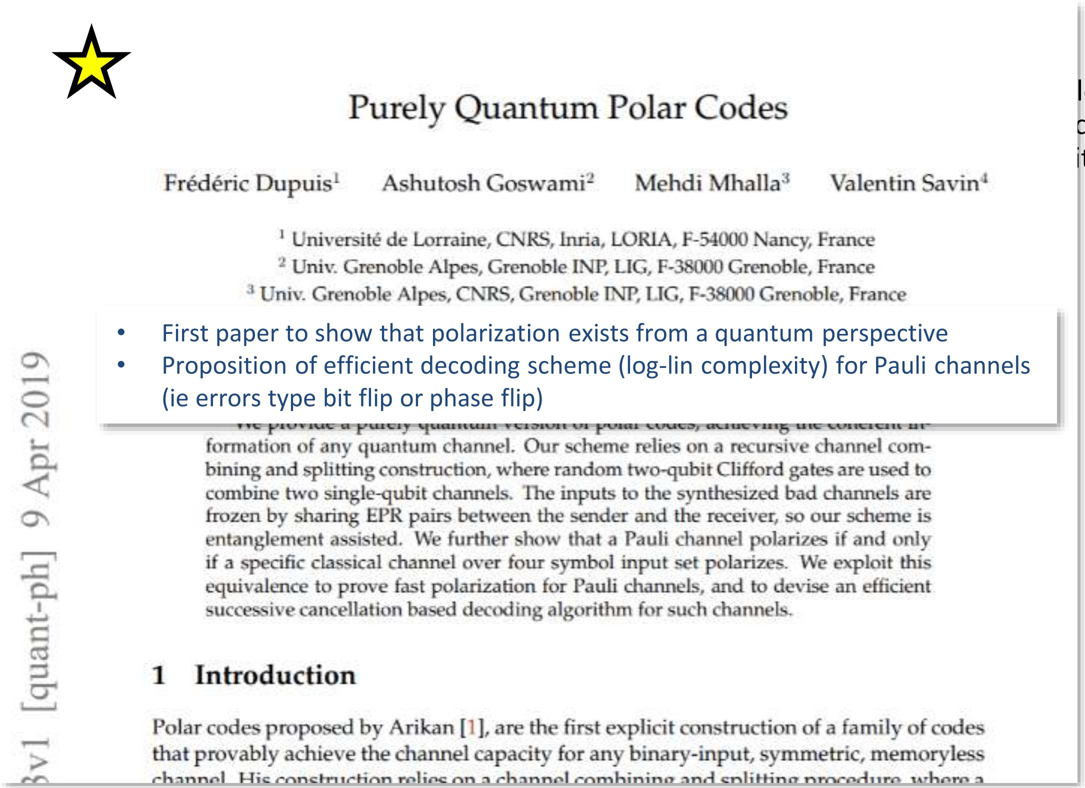




ZX calculus is a EU lead consortium aiming at developing **a full stack intelligent compiler** (indust

1 D … les
u … d
tl … its.
h

2 N
h



Purely Quantum Polar Codes

Frédéric Dupuis[1] Ashutosh Goswami[2] Mehdi Mhalla[3] Valentin Savin[4]

[1] Université de Lorraine, CNRS, Inria, LORIA, F-54000 Nancy, France
[2] Univ. Grenoble Alpes, Grenoble INP, LIG, F-38000 Grenoble, France
[3] Univ. Grenoble Alpes, CNRS, Grenoble INP, LIG, F-38000 Grenoble, France

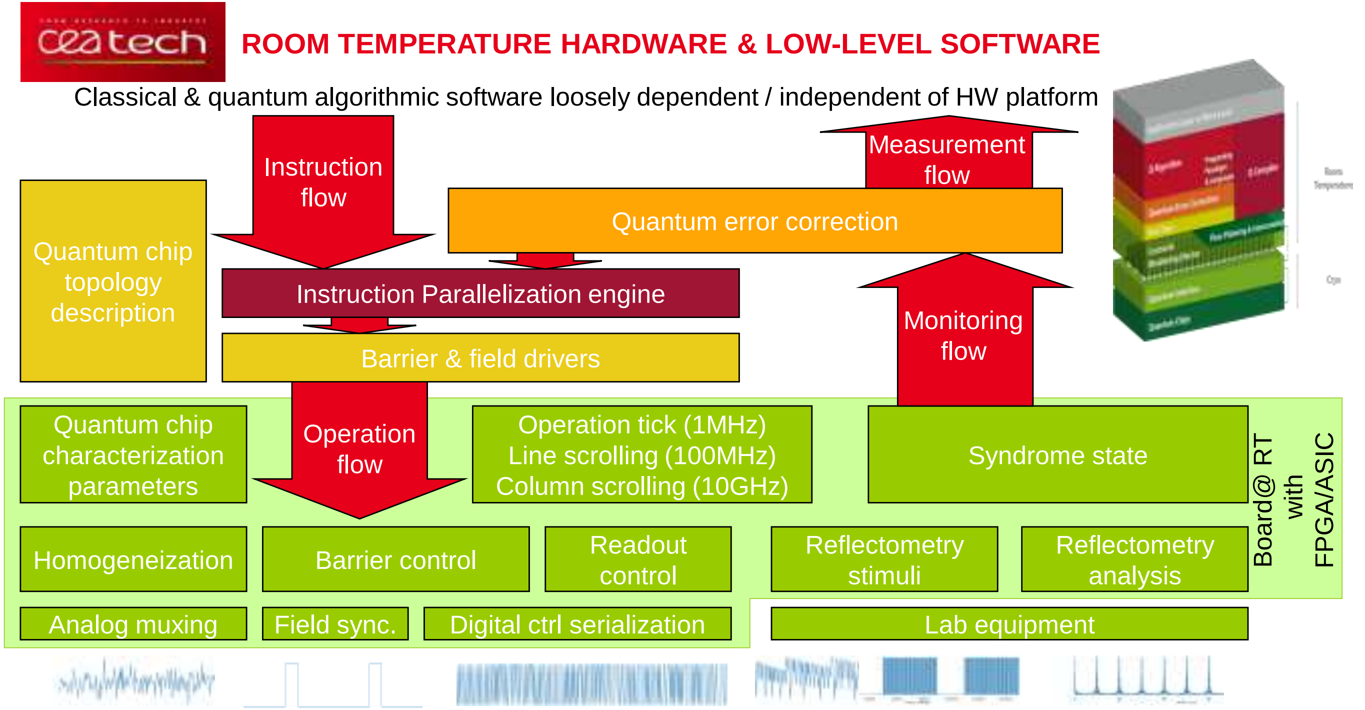
… formation of any quantum channel. Our scheme relies on a recursive channel combining and splitting construction, where random two-qubit Clifford gates are used to combine two single-qubit channels. The inputs to the synthesized bad channels are frozen by sharing EPR pairs between the sender and the receiver, so our scheme is entanglement assisted. We further show that a Pauli channel polarizes if and only if a specific classical channel over four symbol input set polarizes. We exploit this equivalence to prove fast polarization for Pauli channels, and to devise an efficient successive cancellation based decoding algorithm for such channels.

1 Introduction

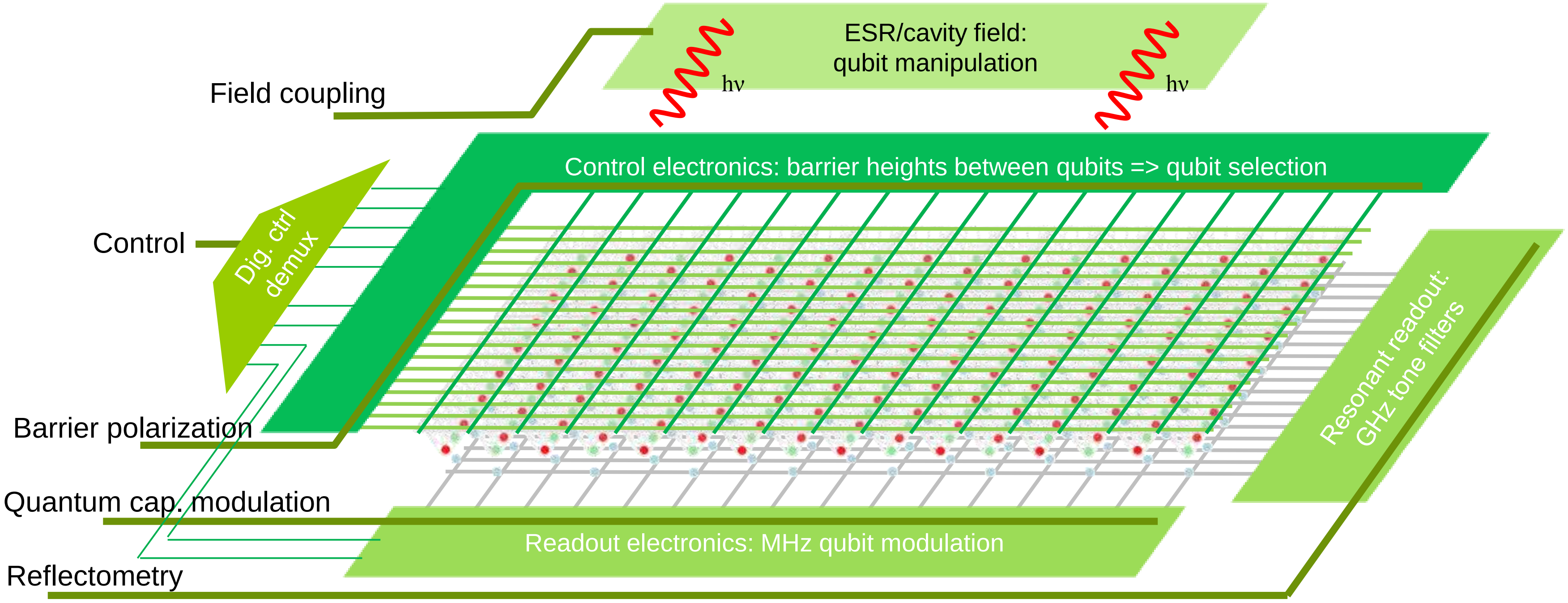
Polar codes proposed by Arikan [1], are the first explicit construction of a family of codes that provably achieve the channel capacity for any binary-input, symmetric, memoryless channel. His construction relies on a channel combining and splitting procedure, where a …

- First paper to show that polarization exists from a quantum perspective
- Proposition of efficient decoding scheme (log-lin complexity) for Pauli channels (ie errors type bit flip or phase flip)

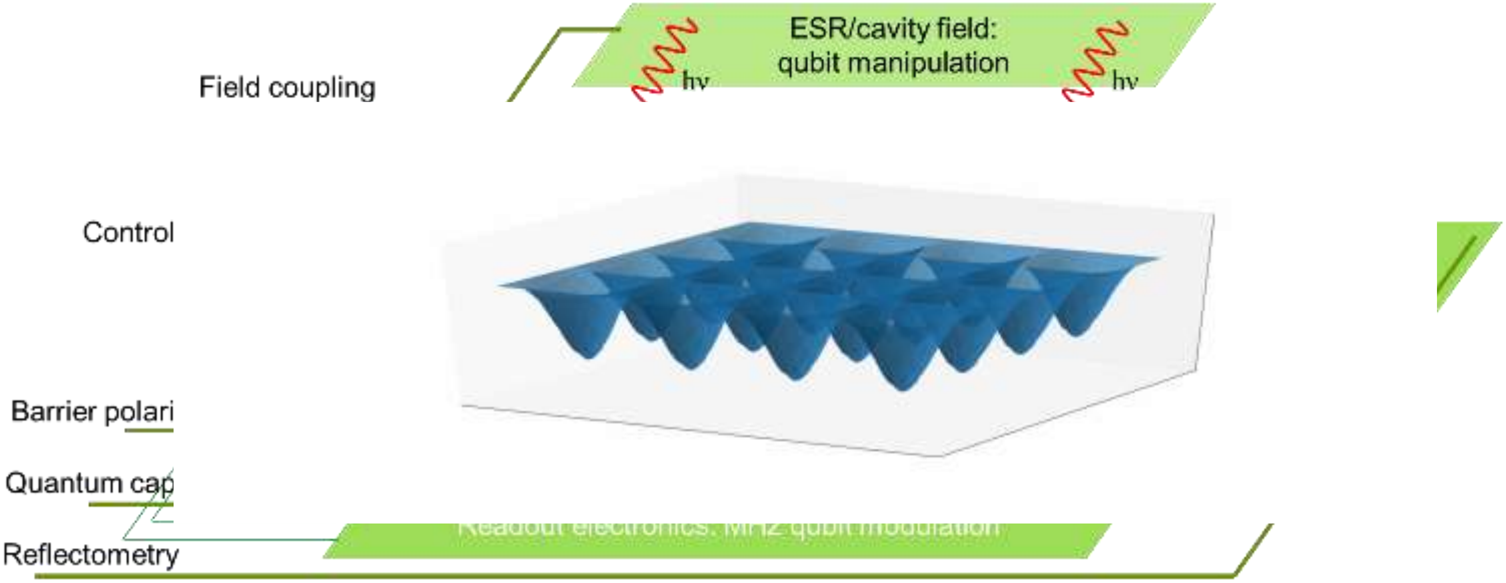
Architecture highlights



CONTROL ELECTRONICS AND CHIP ARCHITECTURE



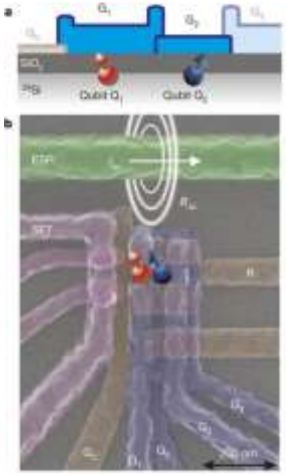
Architecture definition v0 (must have)



CONCLUSION

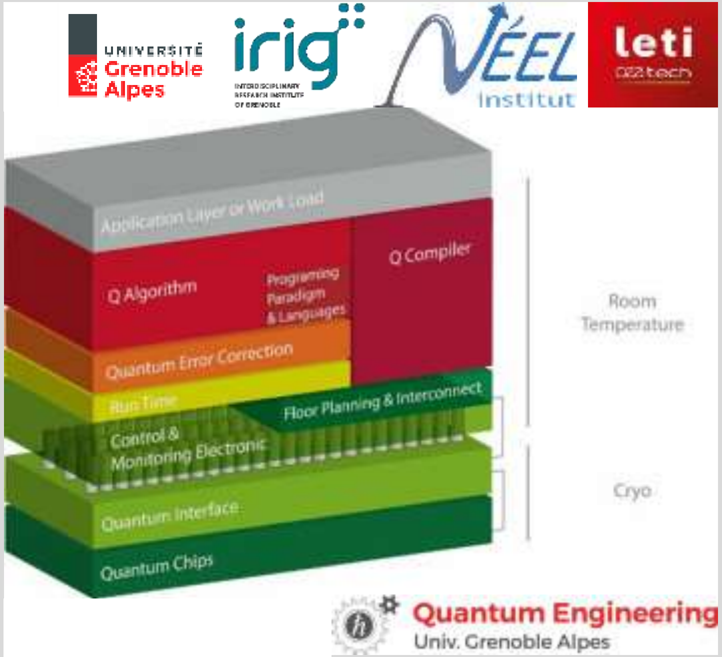
Quantum computing is a **disruptive innovation** in computing.
French industrial and research ecosystem is **at the state-of-the-art**

State of the art



UNSW, 2015

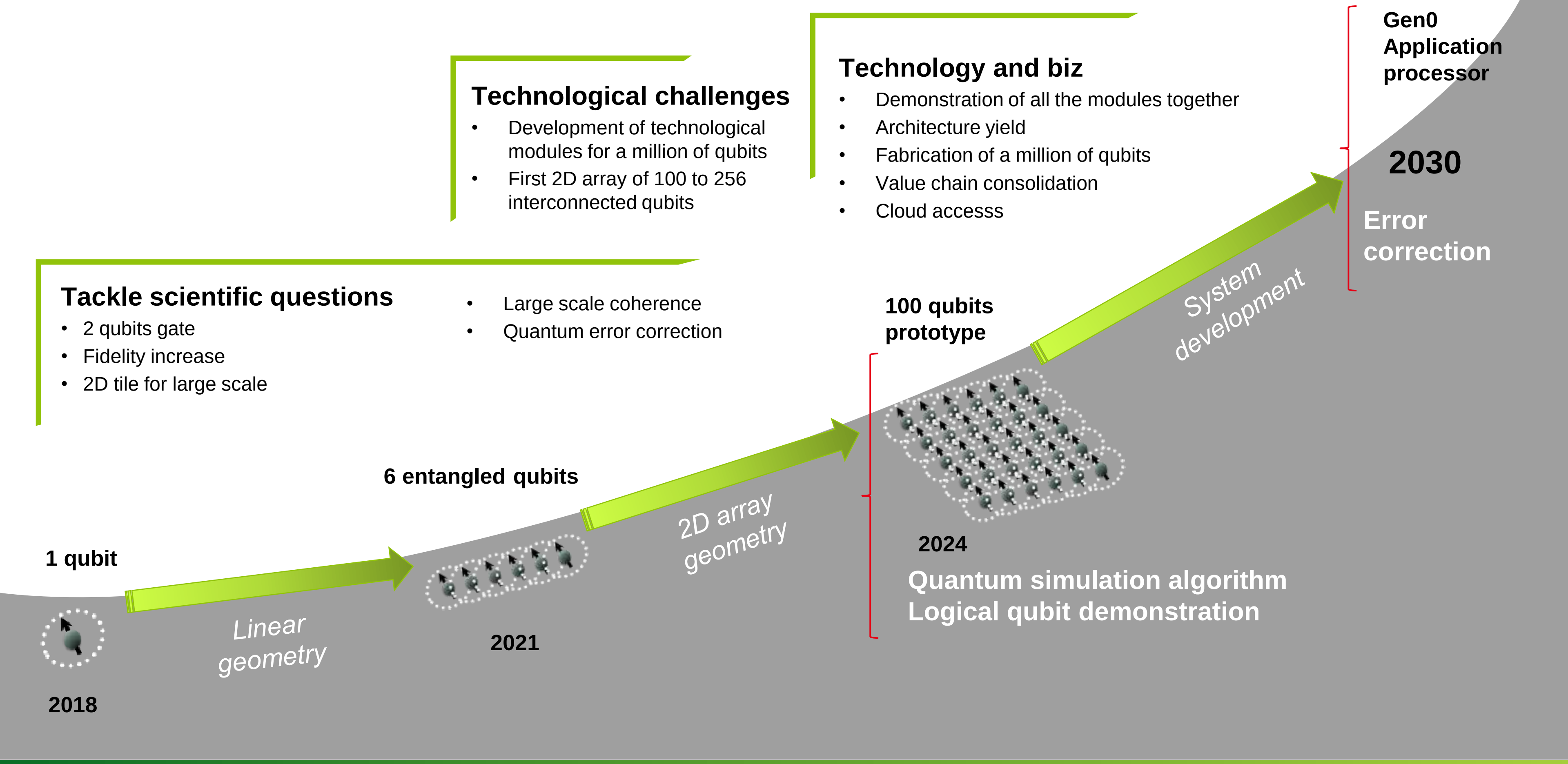
Grenoble Quantum Program



Motivation & positioning

- Become the hardware leader in terms of qubits quality & quantity
- Interlock with users ecosystem to optimize usage-hardware design

SI SPIN QC ROADMAP



Leverage collective intelligence

60000 students, 100 researchers in fundamental quantum sciences

- Philosophy
- Social sciences

Quantum physics

- Condensed matter
- Nanosciences
- Photonics

- **Computer sciences**
- Mathematics

- Create the feeling of belonging to an adventure
- Leverage the physicist for risk analysis and for finding problems
- Leverage the engineering skills to propose solutions and move on (open and close doors)

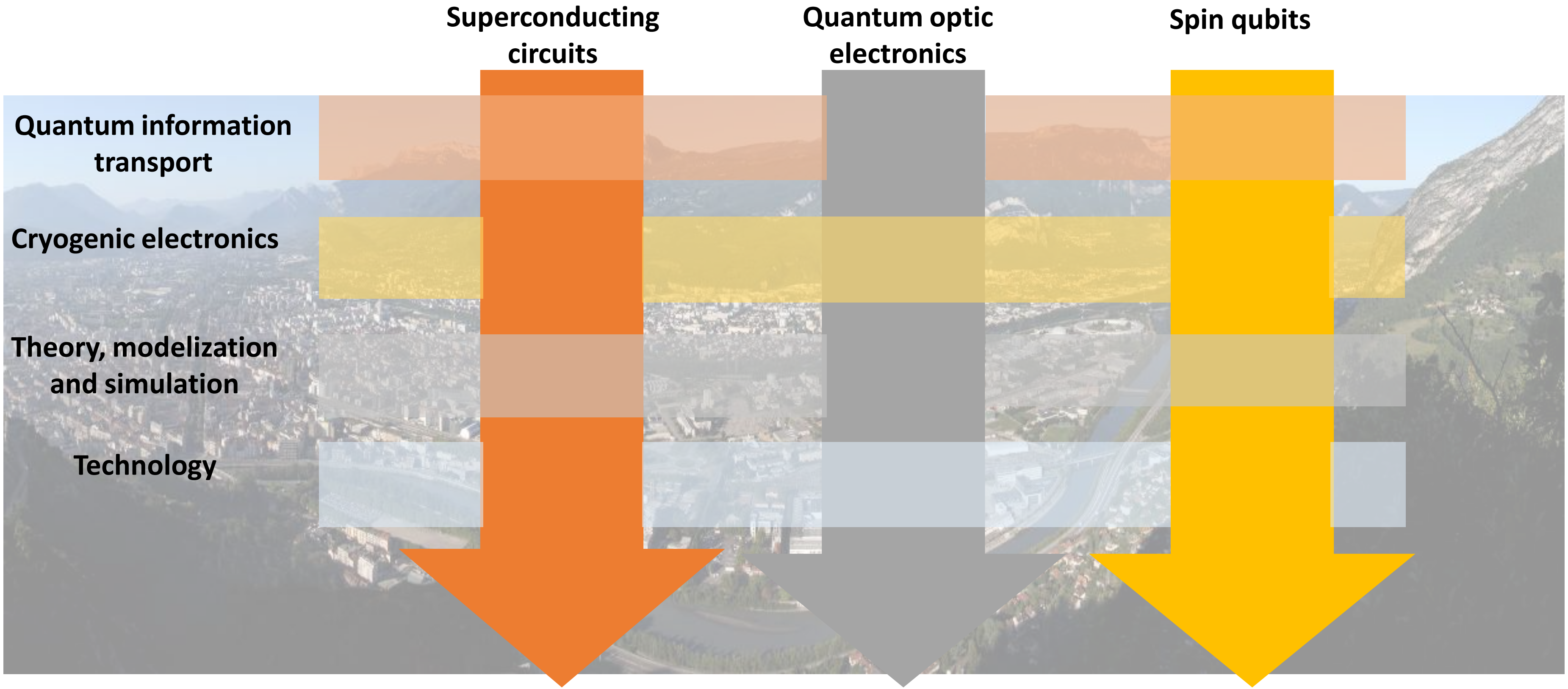
Quantum Engineering
Univ. Grenoble Alpes

- **Industry**
- **Entrepreneurship**

Engineering

- Large scale facilities
- Nanotechnologies

QuantECA: Large scale quantum integration



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