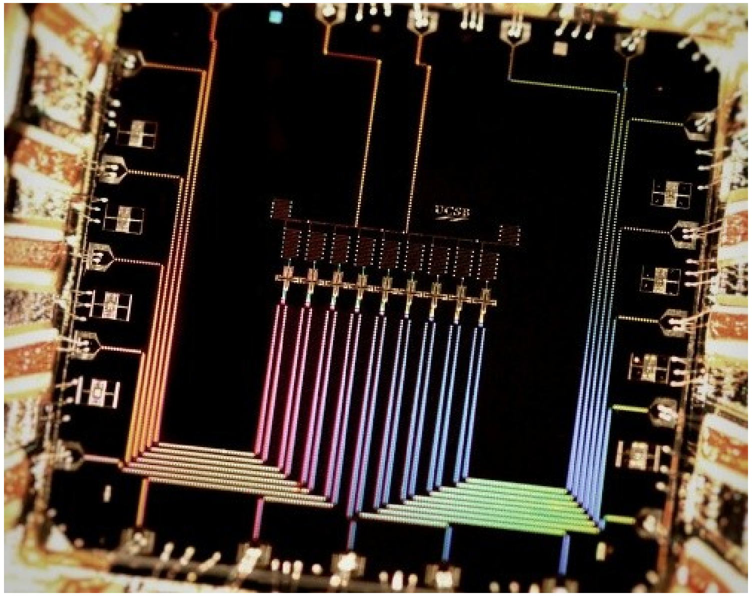
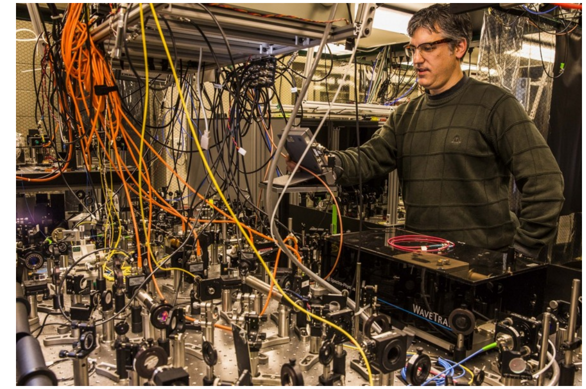
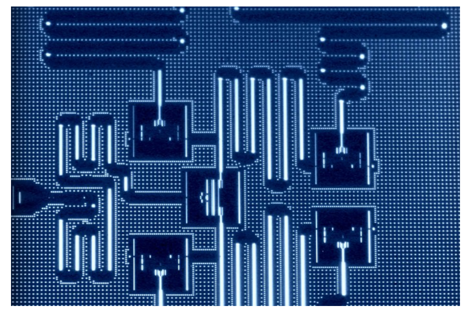


Martinis (Google)



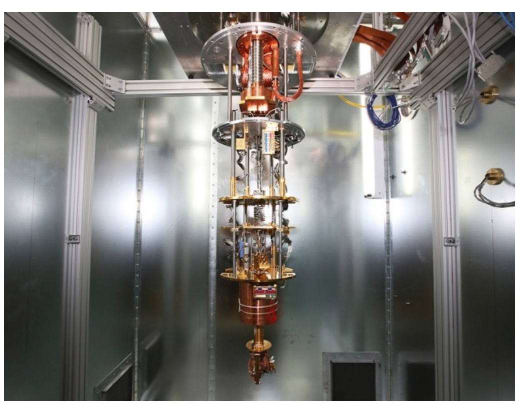
ionQ



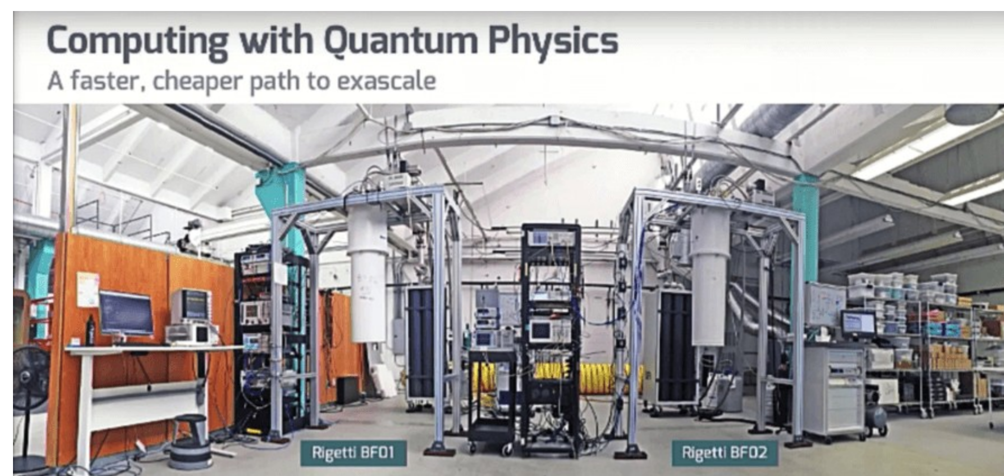
IBM cloud computer

STATION Q

Microsoft



DWAVE2



Rigetti

+LABS all over the world

QuanTic@BSC-UB

Experimental group

Coherent Quantum Annealer

Theory group

Algorithms

Coherent Quantum Annealing

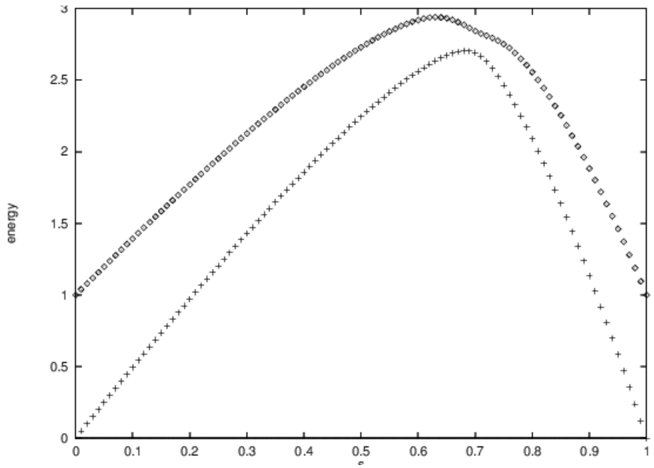
(not a full quantum computer)

Adiabatic Quantum Evolution

$$H = (1 - s) H_0 + s H_P$$

Easy to prepare

Minimum energy solves a problem



Slow evolution stays in the groundstate

Hard problem = exponentially small gap

Travelling Salesman Problem (NP-complete)

$$z_{ij} = \frac{1}{2}\left(\sigma_{ij}^{z} - 1\right)$$

City i-th is visited in j-th position = 0 (no) or 1 (yes)
d_ik is the distance between cities i-th and k-th

$$H_P = \sum_i \left(\sum_j z_{ij} - 1\right)^2 + \sum_j \left(\sum_i z_{ij} - 1\right)^2 + \sum_{ikj} \left(z_{ij}\, z_{k(j+1)}\, d_{ik}\right)$$

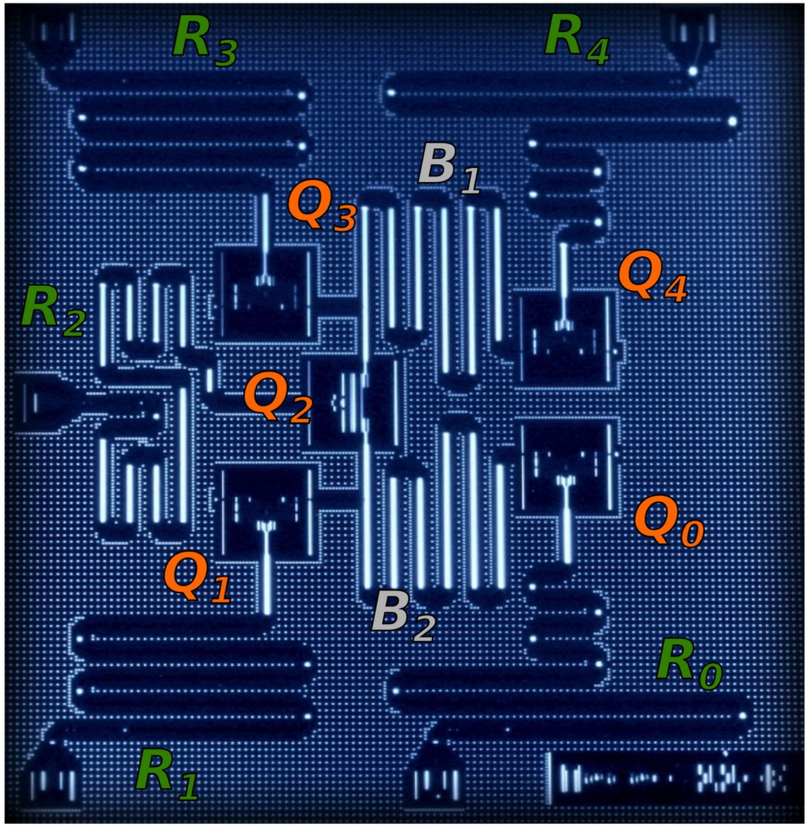
Quantum Annealing
can accommodate any quadratic optimization problem

$$H_P = \sum_{ij} A_{ij} \sigma_i^z \sigma_j^z$$

There is a race to map classical optimization problems to a quadratic form!!

Easy entry level for new pragmatic students

Algorithms



superconducting qubits

IBM Quantum Experience 2016

5-qubit full quantum computer

Available unary gates:

$$\sigma_x \, \sigma_y \, \sigma_z$$

$$H$$

$$T = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{4}} \end{pmatrix} \quad S = \begin{pmatrix} 1 & 0 \\ 0 & e^{i\frac{\pi}{2}} \end{pmatrix}$$

CNOT only targeted to one qubit

Not all gates have equal quality!!!!

Mermin inequalities

Alsina, JIL

$$M_3 = (a_1' a_2 a_3 + a_1 a_2' a_3 + a_1 a_2 a_3') - (a_1' a_2' a_3')$$

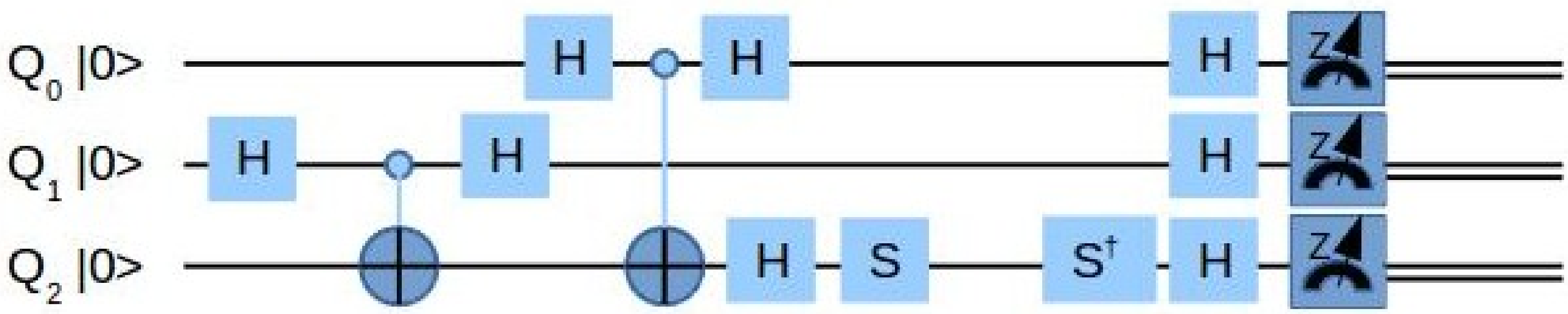
$$M_3^2 = 4I - [a_1, a_1'][a_2, a_2'] - [a_1, a_1'][a_3, a_3'] - [a_2, a_2'] - [a_3, a_3']$$

$$\langle M_3 \rangle^{LR} \leq 2 \qquad \langle M_3 \rangle^{QM} \leq 4$$

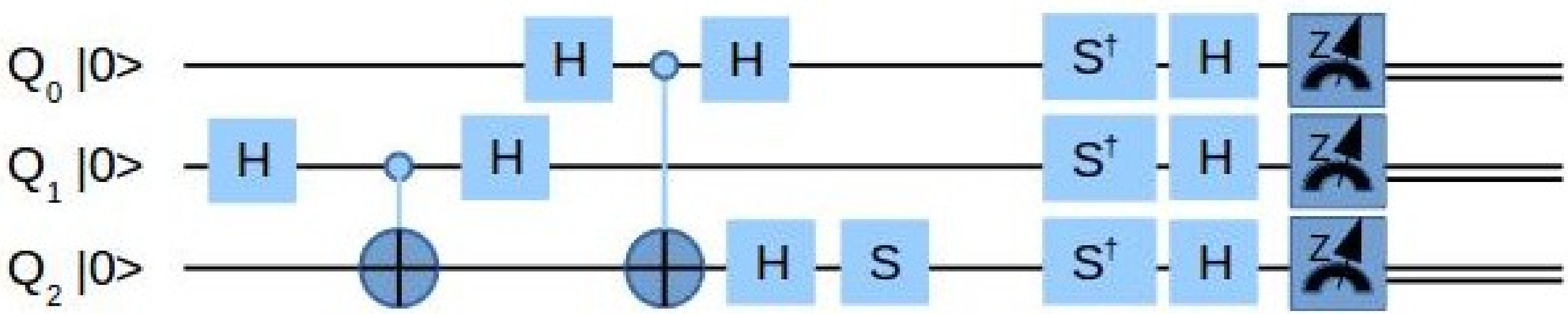
$$|\psi\rangle = \frac{1}{\sqrt{2}} \left(|000\rangle + i|111\rangle \right)$$

$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|000\rangle + i|111\rangle\right)$$

XXY



YYY



Results

Result XXY	**000**	*001*	*010*	**011**	*100*	**101**	**110**	*111*
Probability	0.229	0.042	0.024	0.194	0.043	0.203	0.231	0.033
Result YYY	**000**	*001*	*010*	**011**	*100*	**101**	**110**	*111*
Probability	0.050	0.188	0.188	0.028	0.258	0.026	0.041	0.221

	LR	QM	EXP
3 qubits	2	4	**2.85± 0.02**
4 qubits	4	$8\sqrt{2}$	**4.81± 0.06**
5 qubits	4	16	**4.05± 0.06**

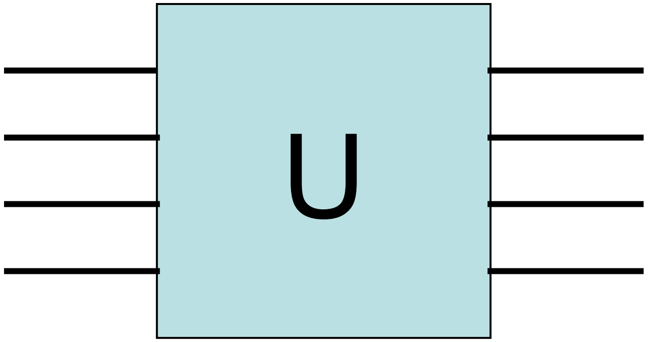
Violation of 3- and 4-qubit

5-qubit remains very poor

Quantum Simulation of a Quantum Phase Transition

Alsina, Hebenstreit, Kraus, JIL

Prepare
a product state



Obtain
the ground state Ising

$$\left|\psi\right\rangle_{ISING} = U\left|\psi\right\rangle_{trivial}$$

Thermal states

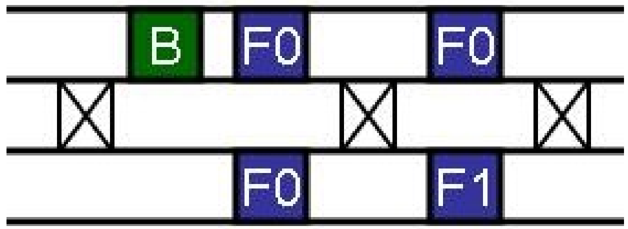
$$e^{-\beta H_{ISING}} = Ue^{-\beta H_{trivial}}U^{+}$$

Quantum circuit for 4-qubit Ising

$$H_{QI} = \sum_i \sigma_i^x \sigma_{i+1}^x + \lambda \sum_i \sigma_i^z$$

$$U(F0) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \frac{1}{\sqrt{2}} & \frac{\alpha}{\sqrt{2}} & 0 \\ 0 & \frac{1}{\sqrt{2}} & -\frac{\alpha}{\sqrt{2}} & 0 \\ 0 & 0 & 0 & -\alpha \end{pmatrix}$$

Bogoliubov

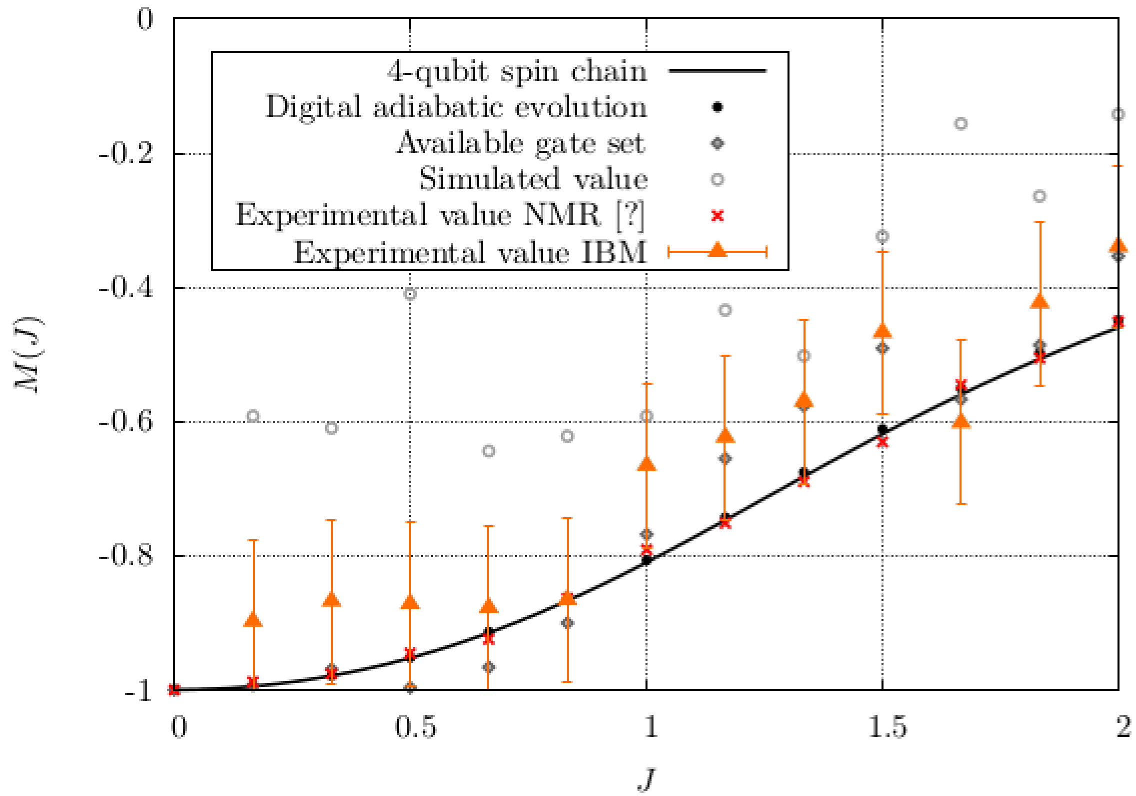


Fast Fourier transform

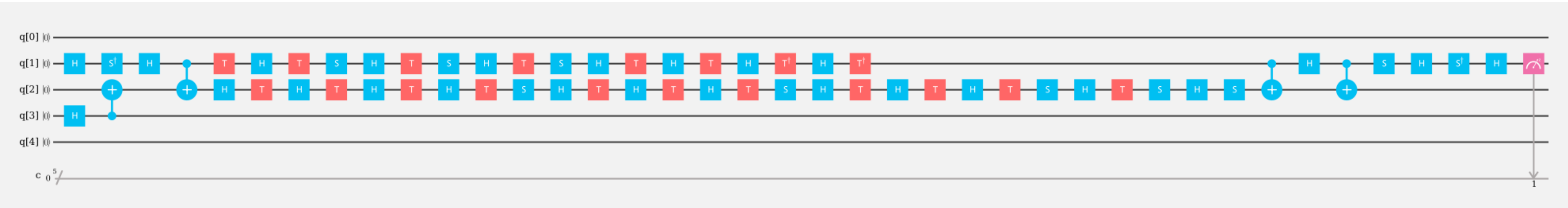
$$U(B) = \begin{pmatrix} \cos(\vartheta(\lambda)) & 0 & 0 & i\sin(\vartheta(\lambda)) \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ i\sin(\vartheta(\lambda)) & 0 & 0 & \cos(\vartheta(\lambda)) \end{pmatrix}$$

Cirac, Verstraete, JIL

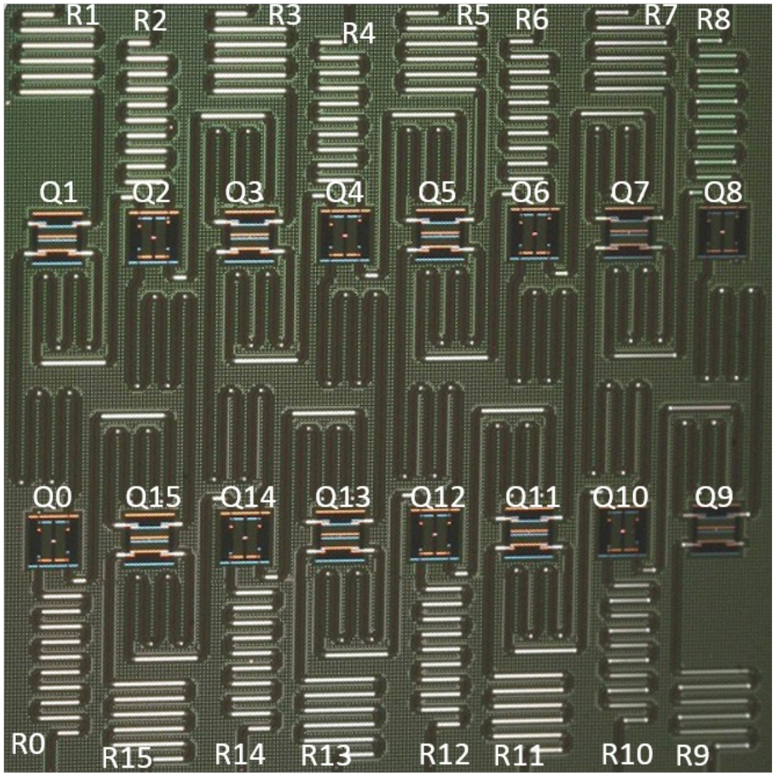
$$U(fSWAP) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

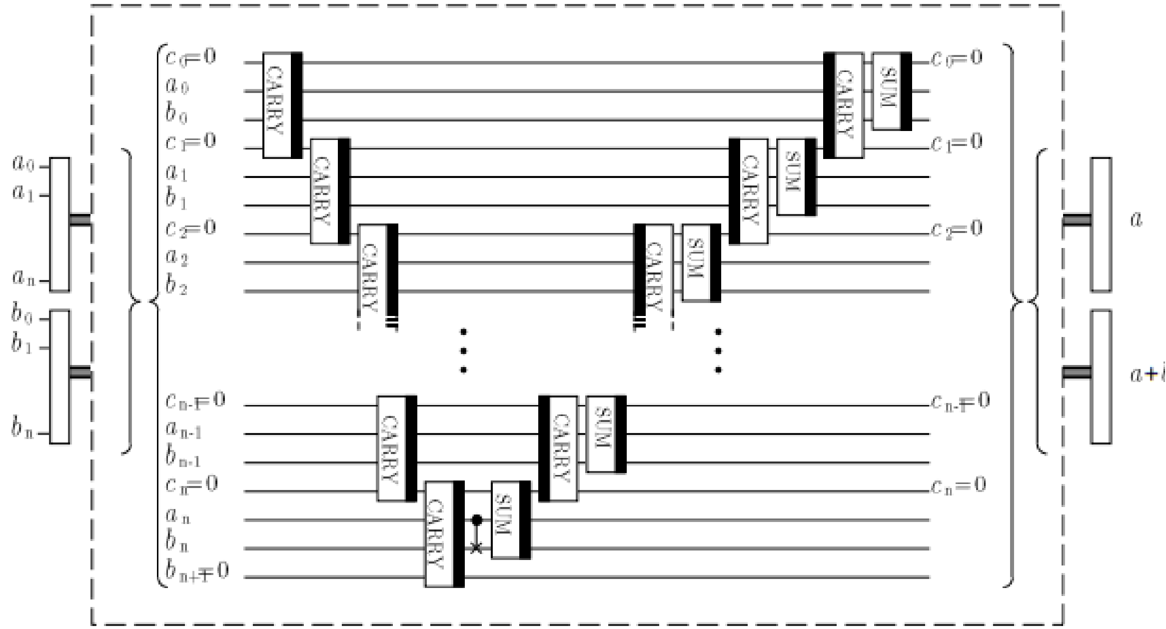


Errors estimated with “validating circuits”



July 2017: 16 qubit cloud quantum computer is available!



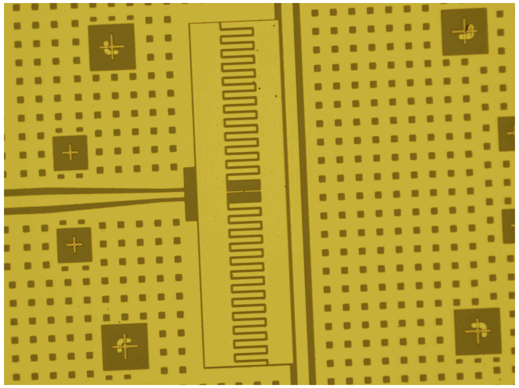



```
1 + 1 = 0 with a probability of  27.63671875 %
1 + 1 = 1 with a probability of  13.671875 %
1 + 1 = 2 with a probability of  46.19140625 %
1 + 1 = 3 with a probability of  12.5 %


Leading result:  1 + 1 = 2
```

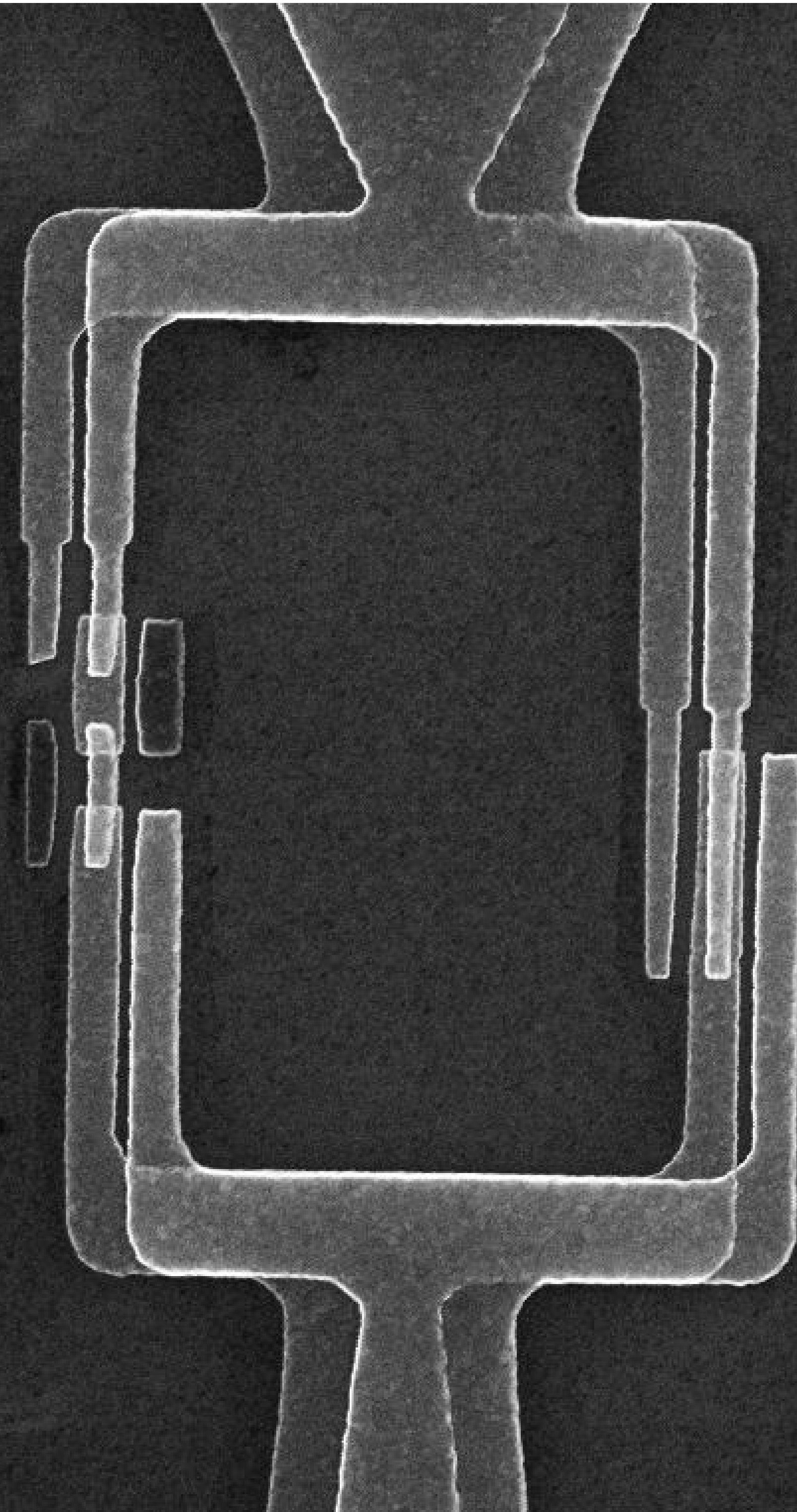
On going

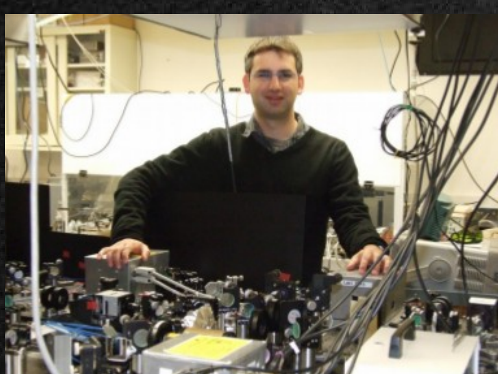
First Qubits!!!



Flux qubits
Novel architectures

Coordinate European consortium of all quantum annealers for the Flagship flux qubit

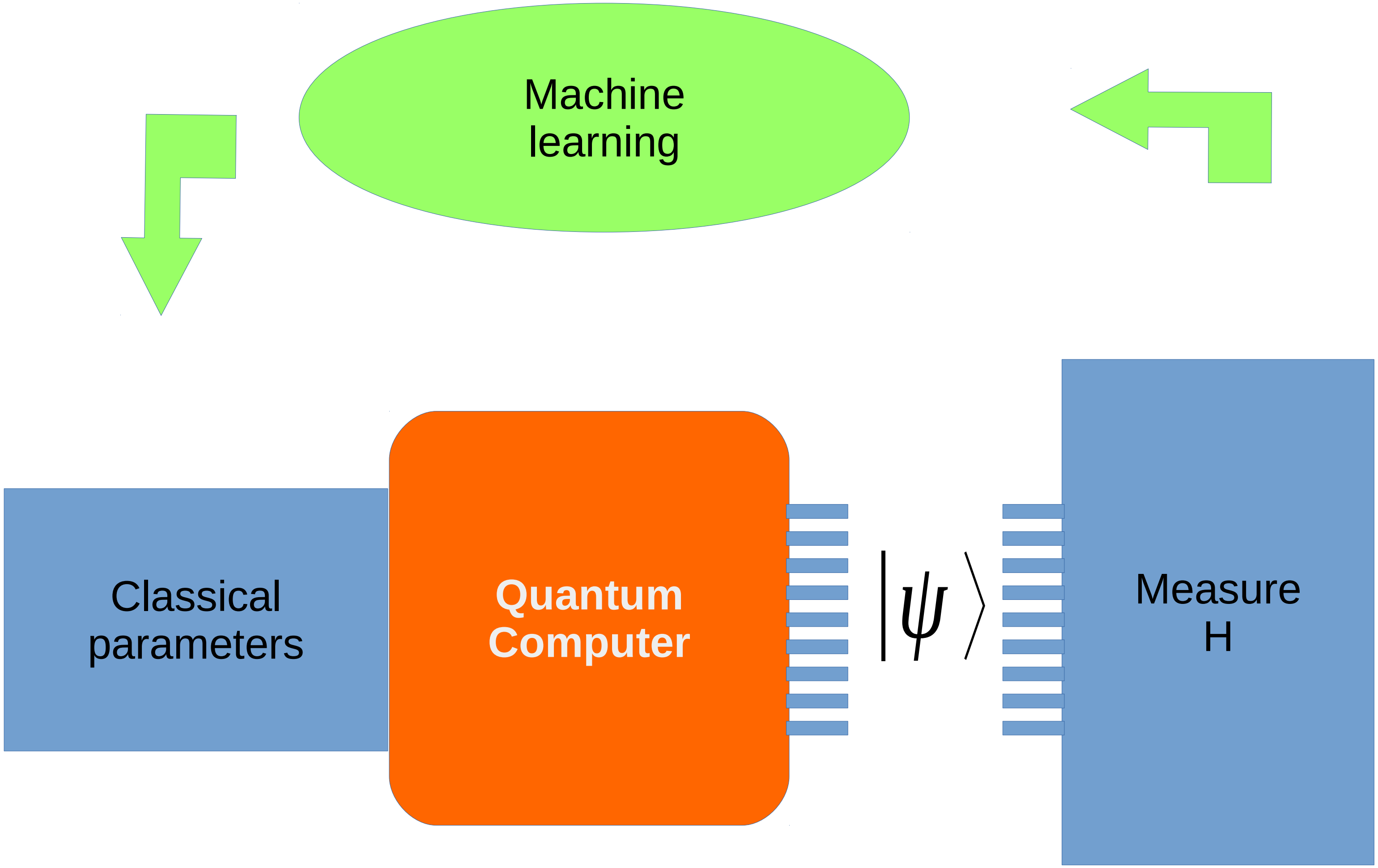




Pol Forn-Díaz

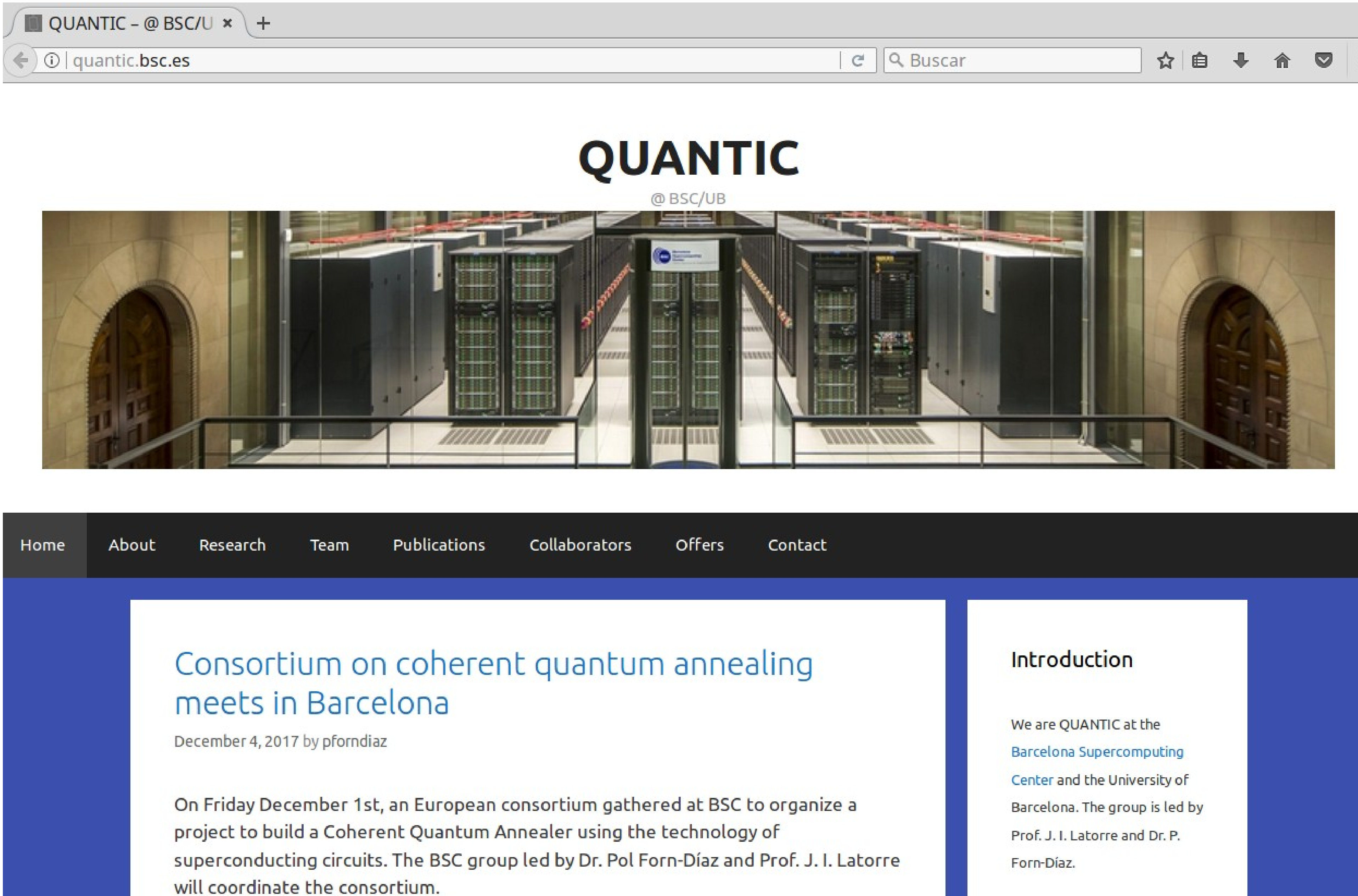
On going

Artur García-Sáez



Variational Quantum Eigensolver Algorithm

THANKS!!!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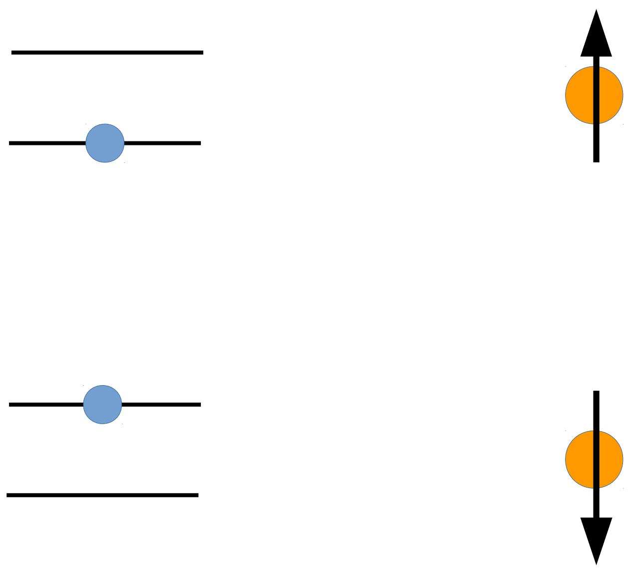
Consortium on coherent quantum annealing meets in Barcelona
December 4, 2017 by pforndiaz
On Friday December 1st, an European consortium gathered at BSC to organize a project to build a Coherent Quantum Annealer using the technology of superconducting circuits. The BSC group led by Dr. Pol Forn-Díaz and Prof. J. I. Latorre will coordinate the consortium.
Introduction
We are QUANTIC at the Barcelona Supercomputing Center and the University of Barcelona. The group is led by Prof. J. I. Latorre and Dr. P. Forn-Díaz.

Quantum Paradigm

Physics | Logical bit



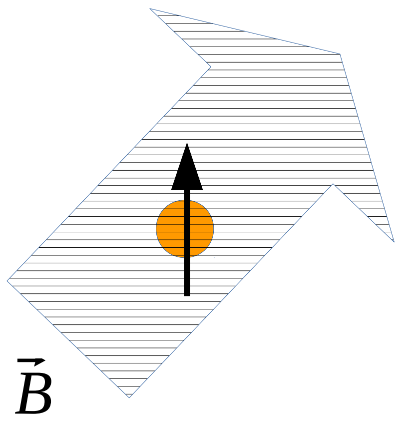
$|0\rangle$

$|1\rangle$

Superposition = QUBIT

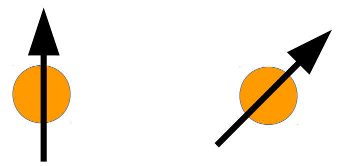
$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle$$

Unitary Evolution = Quantum Gates



$$U_H|0\rangle = \frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle$$

$$U_H|1\rangle = \frac{1}{\sqrt{2}}|0\rangle - \frac{1}{\sqrt{2}}|1\rangle$$



$$U_{CNOT}|00\rangle = |00\rangle \qquad U_{CNOT}|10\rangle = |11\rangle$$

$$U_{CNOT}|01\rangle = |01\rangle \qquad U_{CNOT}|11\rangle = |10\rangle$$

New Logical Gates

Interference

Physical evolution is distributive

$$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \delta|11\rangle$$

$$U|\psi\rangle = \alpha U|00\rangle + \beta U|01\rangle + \gamma U|10\rangle + \delta U|11\rangle$$

n qubits $\qquad$ 2^n simultaneous operations

Evolution = Exponential Parallel Computation

Quantum measurements bring inherent randomness

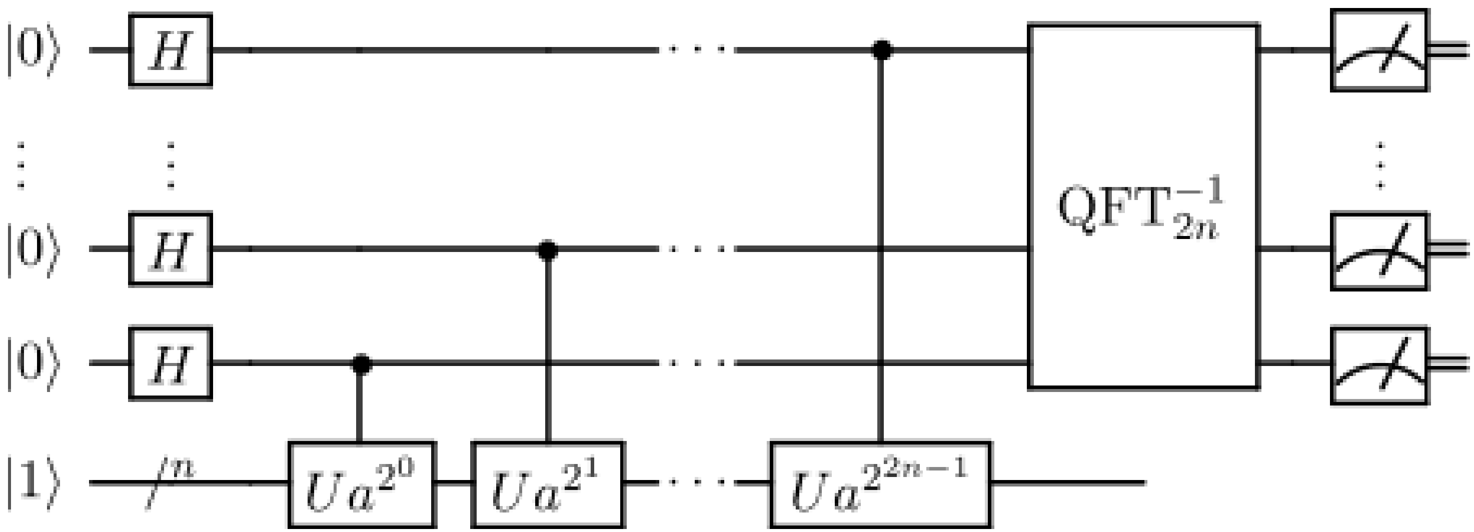
Ex: $$|\psi\rangle = \alpha|00\rangle + \beta|01\rangle + \gamma|10\rangle + \delta|11\rangle$$

$$Prob(00) = |\alpha|^2$$

Measurement randomness has to be circumvented

Example: **Shor's algorithm**

Factorization is as hard as period finding: use a **Quantum Fourier Transform**



Factorization (Quantum Fourier Transform)

Classical Computer

$$e^{\left(\frac{64}{9}\right)^{1/3} n^{1/3} (\log n)^{2/3}}$$

Quantum Computer

$$n^3 (\log n)(\log(\log n))$$

Shor's algorithm is exponentially faster

ALL RSA CRYPTOGRAPHY IS IN DANGER