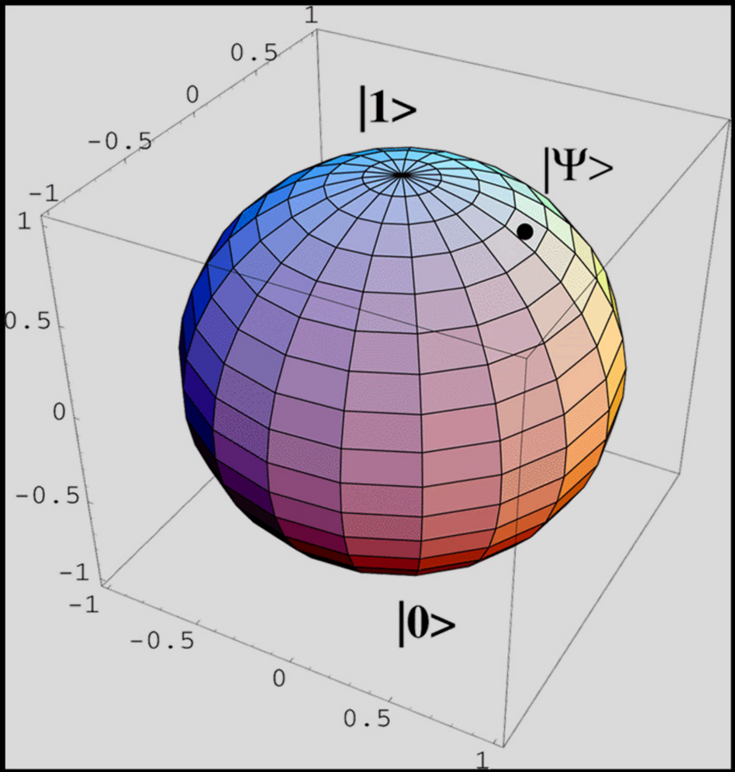
QUANTUM LEARNING

THREE PILLARS OF QUANTUM

- **Quantum superposition principle**
- **Quantum measurements**
- **Quantum correlations – quantum entanglement**

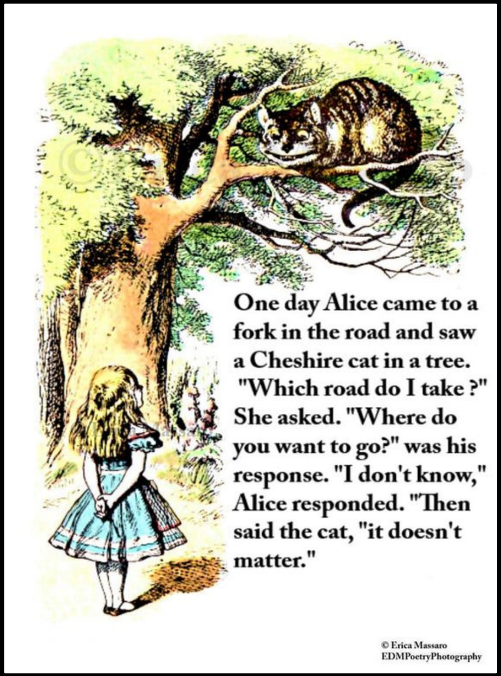
QUBIT – POINCARE SPHERE



QUANTUM MEASUREMENTS

- **Outcome of a measurement performed on a quantum system can only be predicted statistically – with some probability.**
- **Quantum world at a level of classical description is random.**
- **By performing a measurement on a single qubit we obtain a result either "0" or "1", but we can't predict it with certainty.**
- **Information gain *vs* disturbance. Measured quantum system collapses into the state that is registered on the measurement device.**
- ***Properties that were determined by quantum measurements did not exist before the measurements were performed.***

Chris Fuchs



QUANTUM ENTANGLEMENT

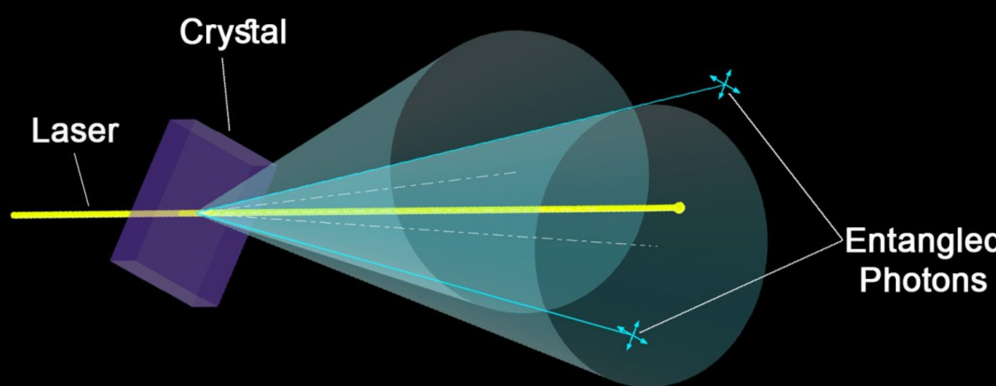
"spooky action at distance"

EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues Find It Is Not 'Complete' Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of 'the Physical Reality' Can Be Provided Eventually.



"If you think you understand quantum mechanics, you don't understand quantum mechanics."

Richard Feynman

PHYSICS & INFORMATION

QUANTUM COMPUTERS ?

"...trying to find a computer simulation of physics, seems to me to be an excellent program to follow out...and I'm not happy with all the analyses that go with just the classical theory, because nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical, and by golly it's a wonderful problem because it doesn't look so easy."

Richard Feynman

QUANTUM INFORMATION TECHNOLOGIES

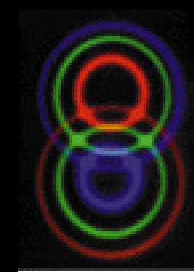
“[QIT] is a radical departure in information technology, more fundamentally different from current technology than the digital computer is from the abacus”.

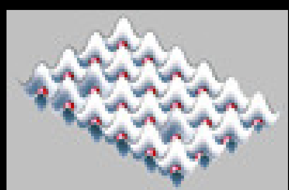
William D. Phillips,

QUANTUM PROCESSORS

Atoms and ions

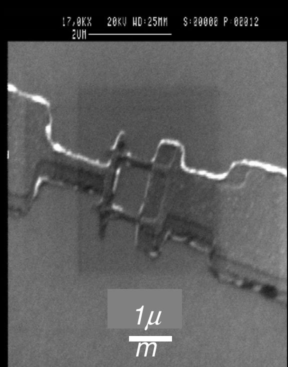
trapped ions and atoms, BEC in optical lattices, atom chips, cavity QED, NMR





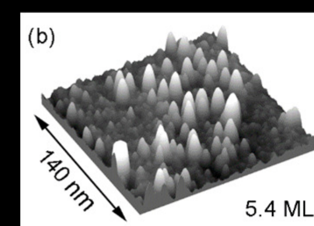
Solid states

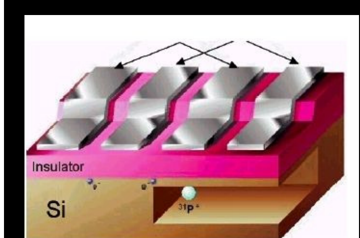
quantum dots, super-conducting qubits systémy, electron spins, nuclear spins

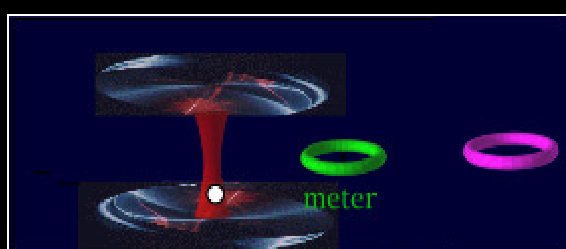


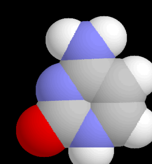
Optical systems

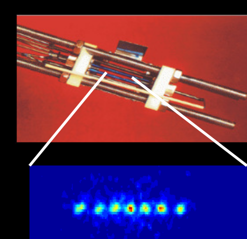
polarization states of photons, KLM scheme, q-crypography

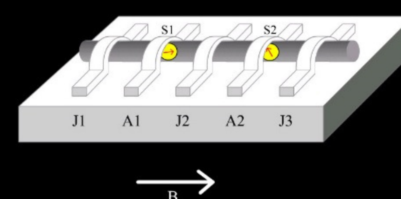




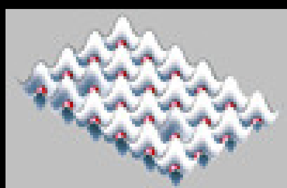


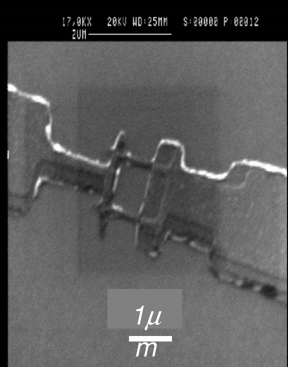


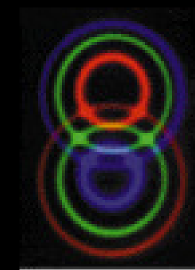


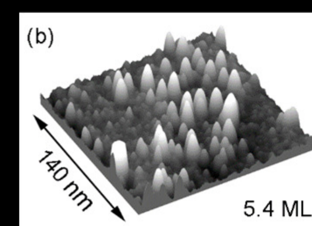


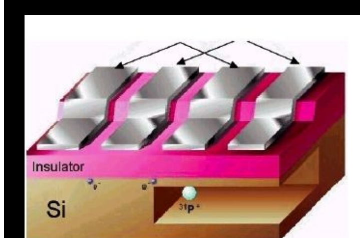
QUANTUM PROCESSORS

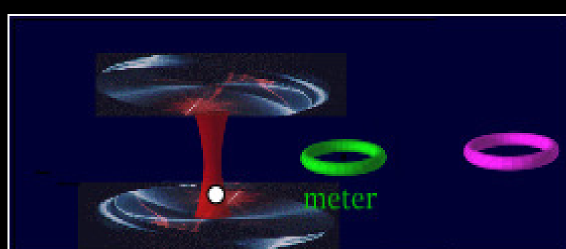


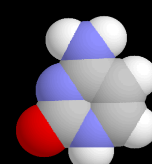


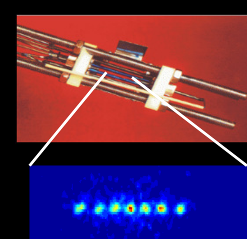


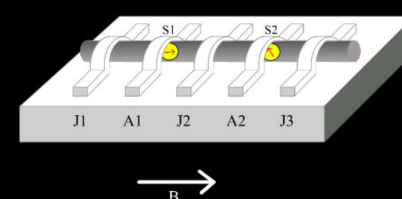










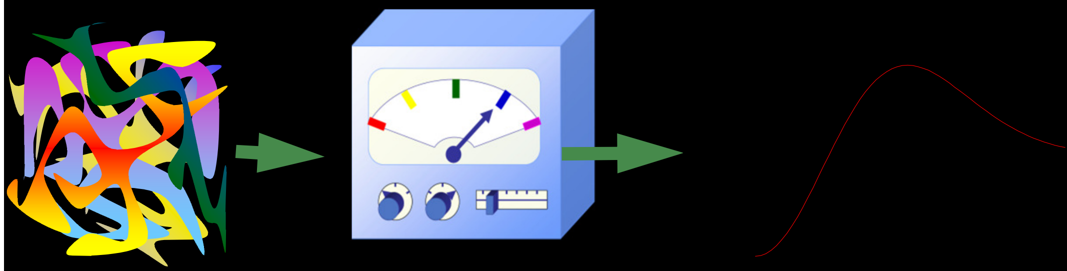


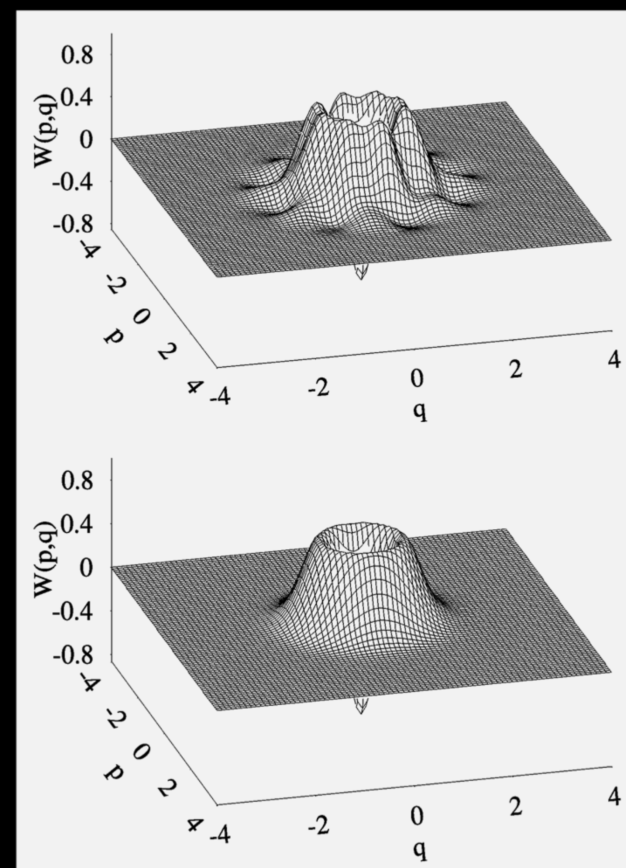
PATHS TO QUANTUM AGI

QUANTUM PATTERN RECOGNITION

Quantum systems produce atypical patterns that classical systems are thought not to produce efficiently, so it is reasonable to postulate that quantum computers may outperform classical computers on machine learning tasks. The field of quantum machine learning explores how to devise and implement quantum software that could enable machine learning that is faster than that of classical computers. Recent work has produced quantum algorithms that could act as the building blocks of machine learning programs, but the hardware and software challenges are still considerable.

Reconstruction of Wigner functions

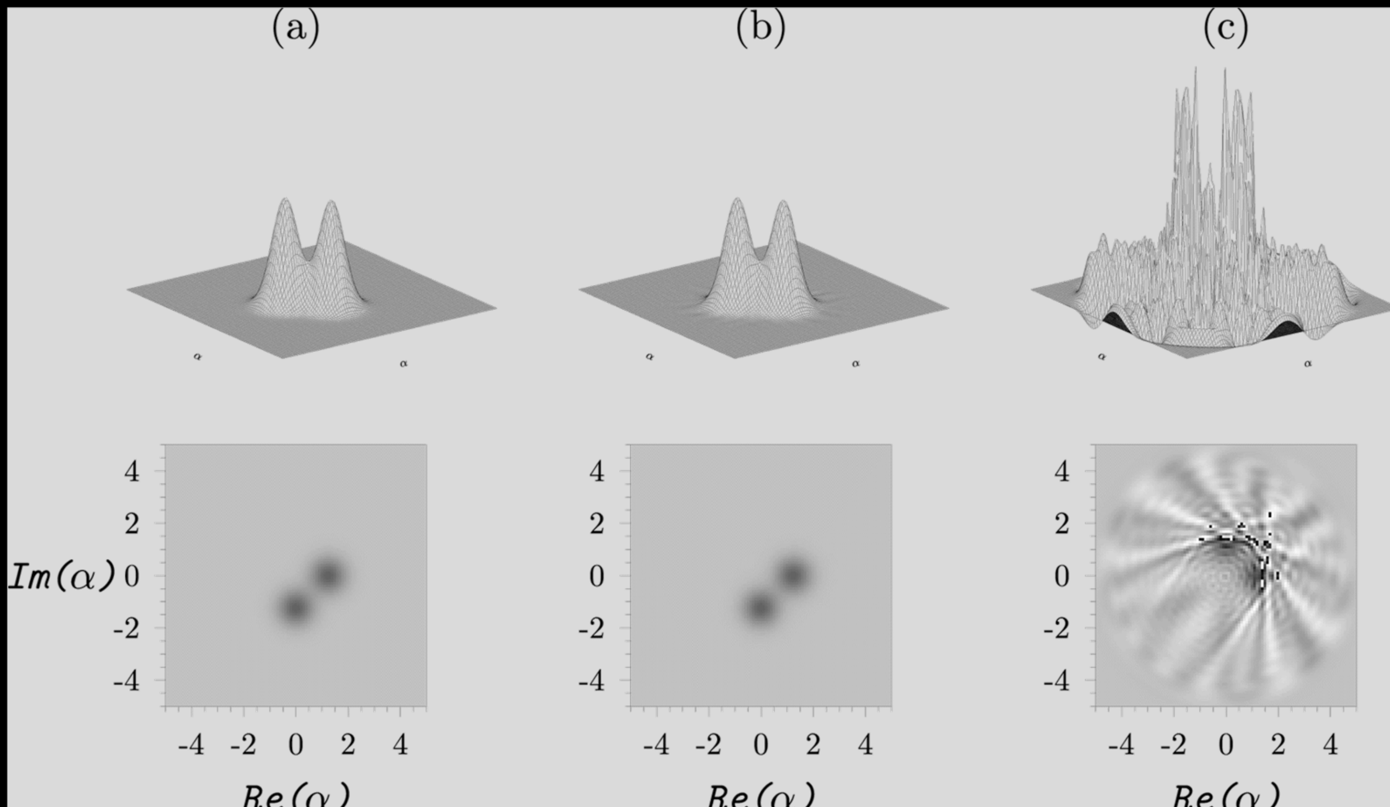




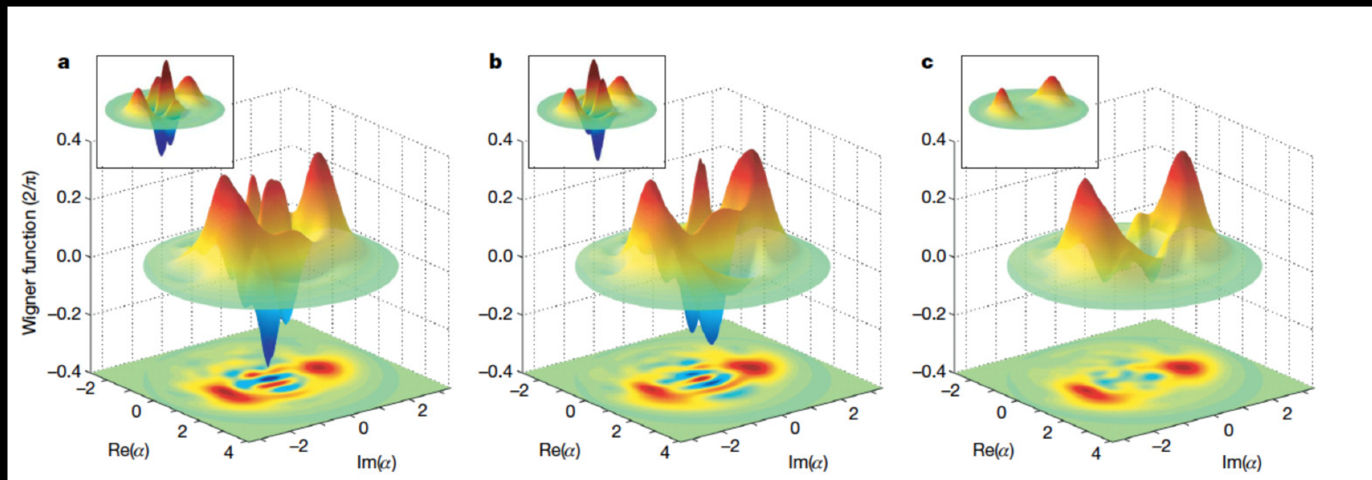
- ***MaxEnt*** *scheme – up to 5 orders more reliable than pattern-function or inverse Radon schemes, requires just 3 distributions for rotated quadratures,*

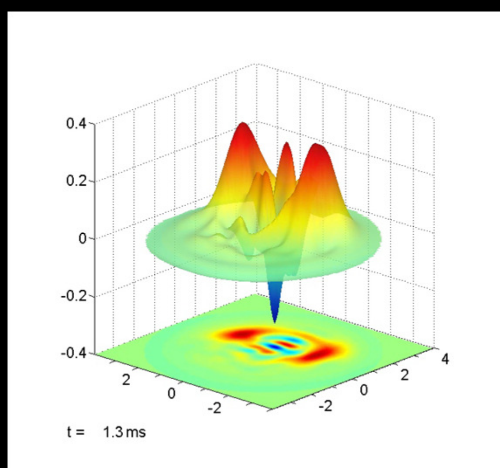
The Wigner function of Fock states of cavity fields from the experimental data obtained at the ENS, Paris obtained from the measurement of a parity operator [P.Bertet et al., PRL. 89, 200402 (2002)]

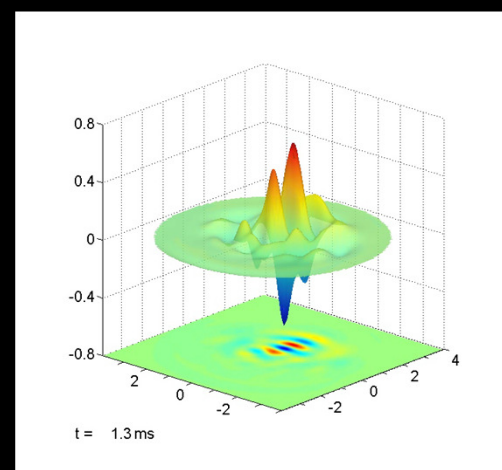
WIGNER FUNCTIONS
from incomplete data



“Collapse” of Schrödinger’s cat







S.Deleglise, I.Dotsenko, C.Sayrin, J.Bernu, M.Brune, J.M.Raimond, S.Haroche, Nature 455, 25 (2008)
V.Bužek and P.L.Knight, Progress in Optics XXXIV, 1-159 (1995)
V.Bužek and G.Drobný, J. Mod. Opt. 47, 2823 (2000)
M.S.Kim and V.Bužek, Phys. Rev. A 46, 4239 (1992)

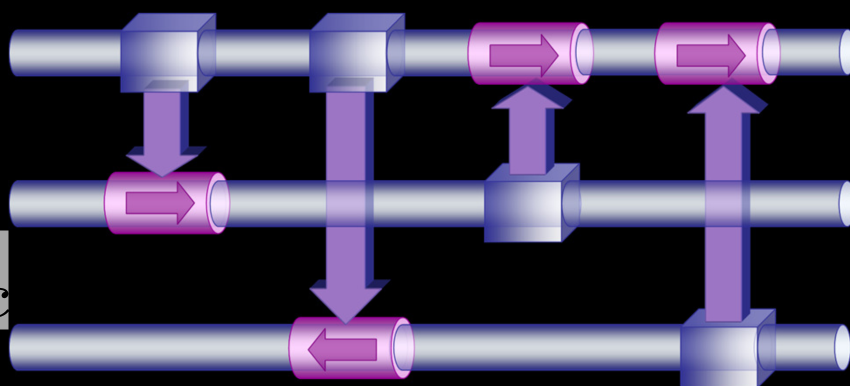
Quantum cloning & U-NOT gate

$$|\psi\rangle_a|0\rangle_b \rightarrow |\psi\rangle_a|\psi\rangle_b$$

$$|\psi\rangle_a \rightarrow |\psi^{\perp}\rangle_a$$

$|\psi\rangle_a$

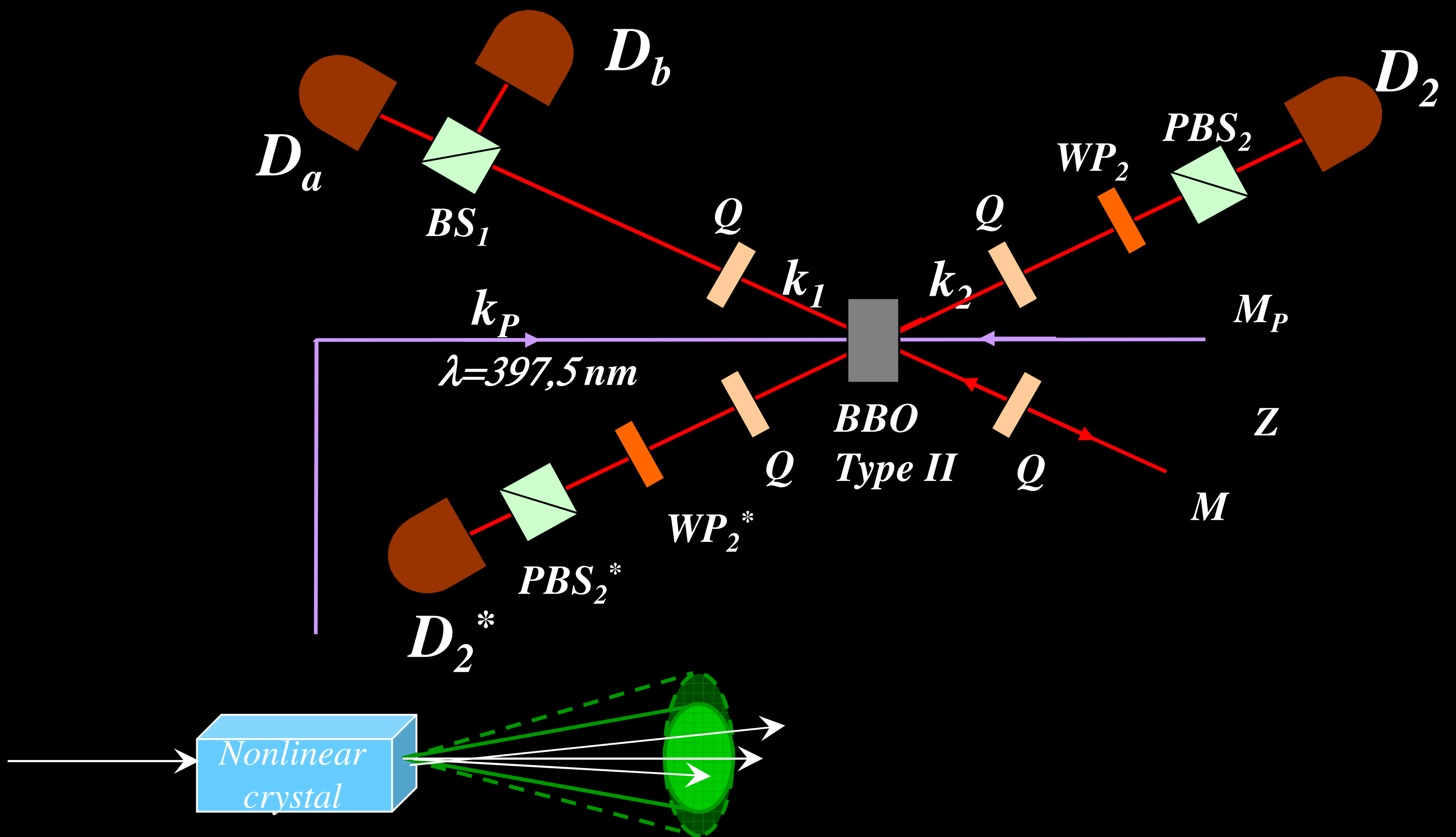
$|\Xi\rangle_{bc}$



C-NOT gate:

$$|k\rangle_a|l\rangle_b \rightarrow |k\rangle_a|(l+k)\mathrm{mod}2\rangle_b$$

Implementation via Optical Parametric Amplifier



F.DeMartini, V.Bužek, F.Sciarino, and C.Sias, Nature 419, 815 (2002).

Black box Problem

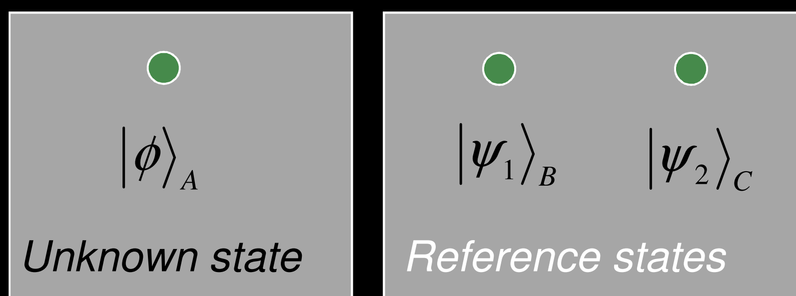
- **How can we determine properties of unknown q-channel (black box with no memory)? We can use qubits as probes and from correlations between in and out states we can determine the map.**

Unambiguous identification

- We are given **3 identical quantum systems** A,B and C in the **product state**

Promise:

- Either subsystems **A** and **B** or subsystems **A** and **C** are prepared in the same state



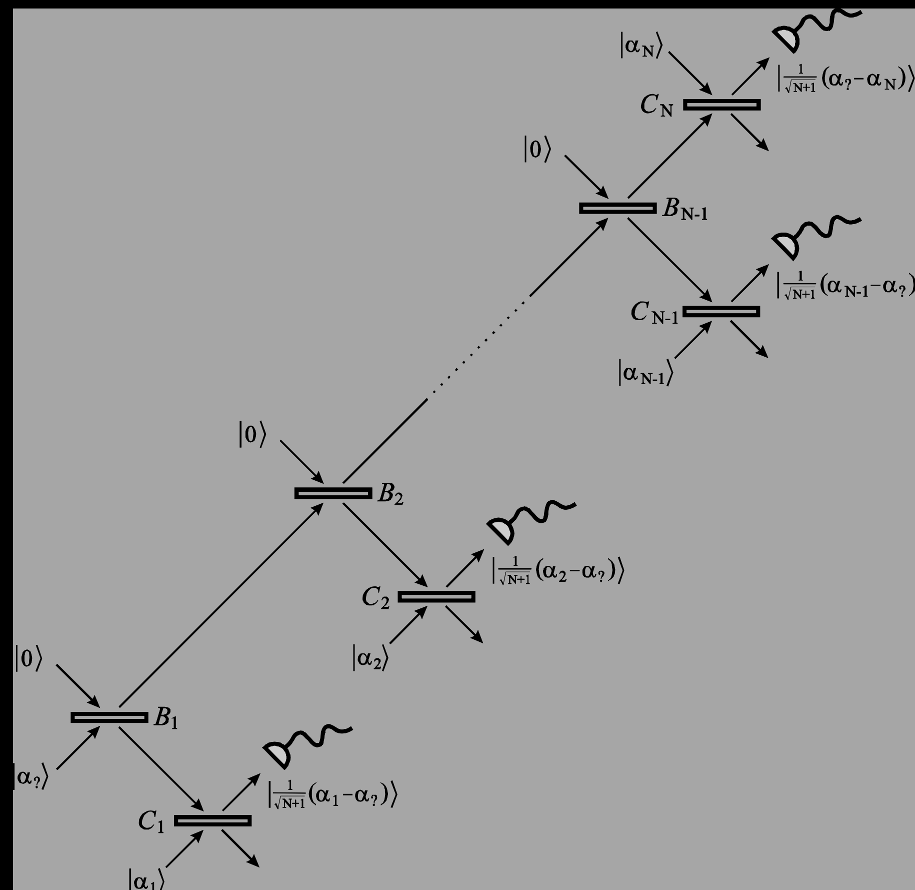
$$|\phi\rangle = |\psi_1\rangle \vee |\phi\rangle = |\psi_2\rangle$$

with a priori probabilities η_1 *resp.* η_2

Task: Unambiguously determine the subsystem which **A** match.

Search in quantum database

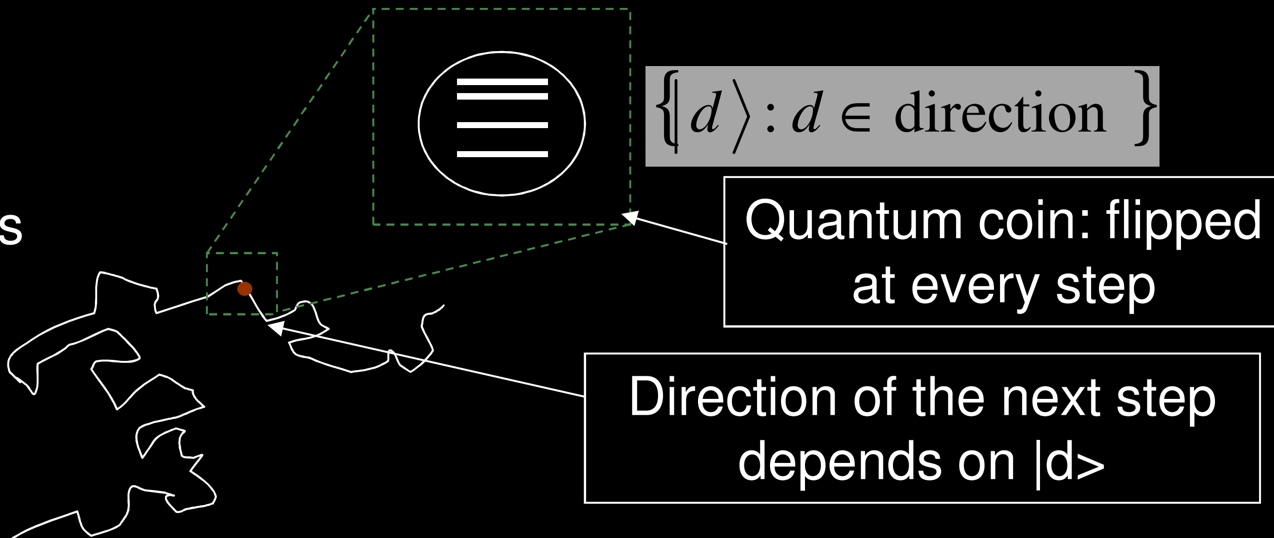
Unambiguous identification of coherent states can be easily performed with beam splitters



Quantum Walks - Search

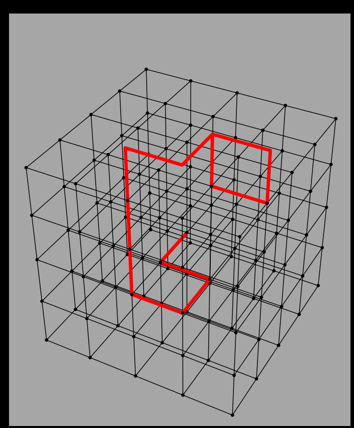
"Quantization" of classical discrete random walks (Markov)

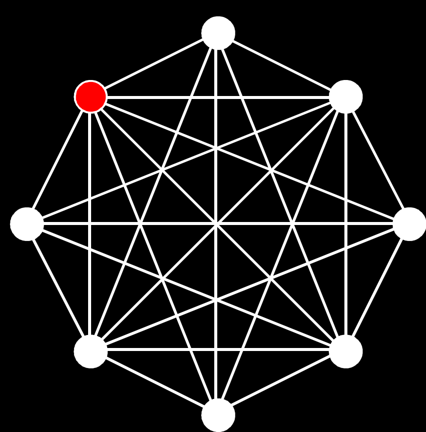
Quadratic/exponential improvement in mixing/hitting properties



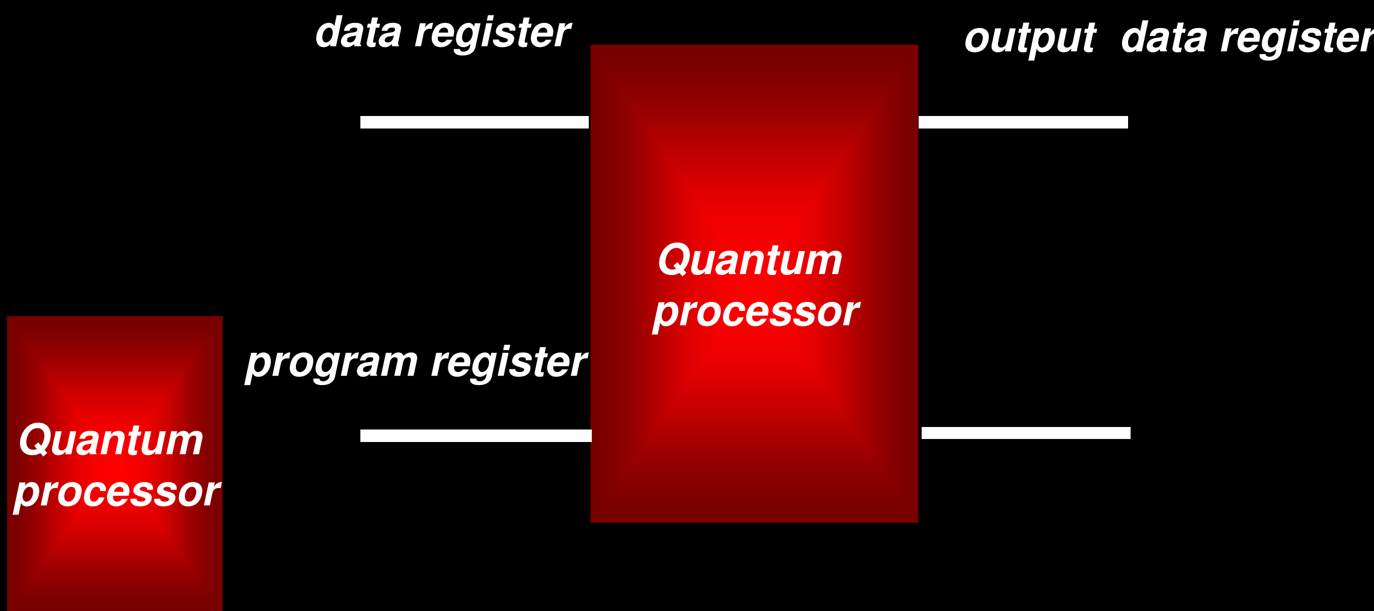
Implementation by means of optical multiports which "flip" the coin.

Multidimensional QRW:





Quantum Processors



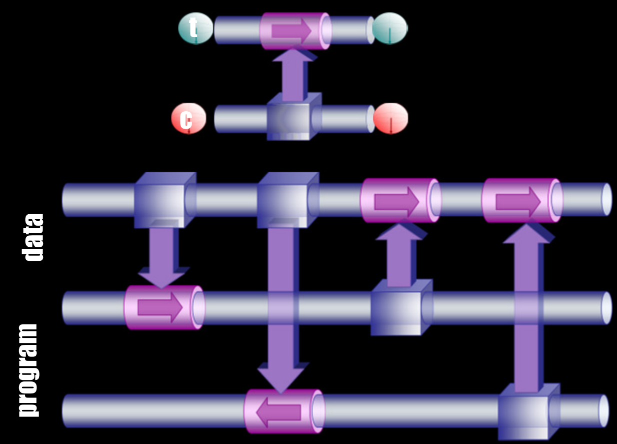
Quantum processor – fixed unitary transformation $\mathbf{U_{dp}}$

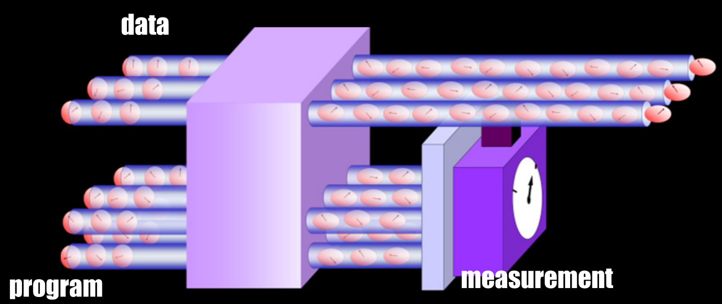
H_d – data system, $S(H_d)$ – data states

H_p – program system, $S(H_p)$ – program states

Programmable Quantum Processors

- **Quantum control** of dynamics, e.g. C-NOT
- **Quantum information distributors** control via input states of two ancillas (prorgam), e.g assymetric cloners or Universal NOT gate (specific processor)
- **NO-GO Theorem** (Nielsen & Chuang) – Universal quantum processors implementing arbitrary program encoded in program registers and applied to data registers do not exist
- **Probabilistic quantum processors** - measurement of program register realizes **arbitrary** map on data register
- **Deterministic processors** – realize specific classes maps



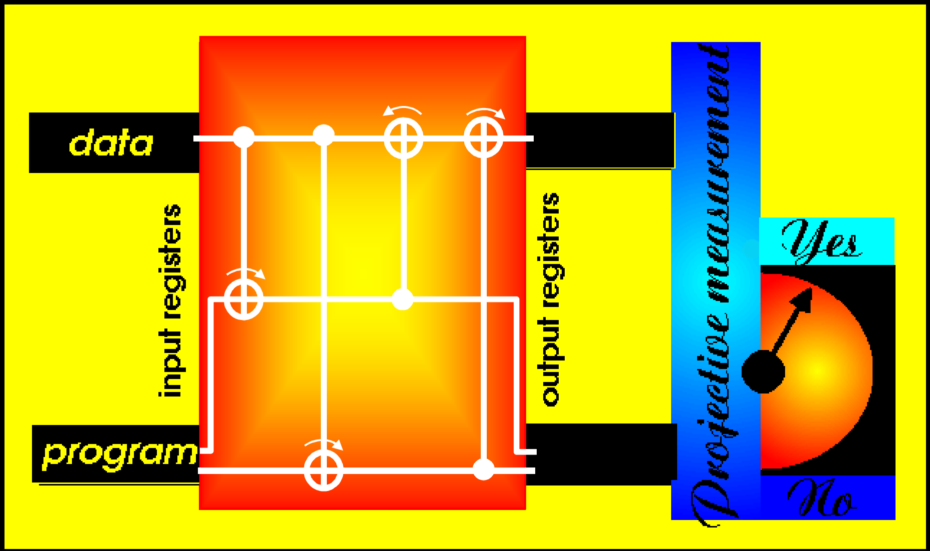


Universal Probabilistic Processor

Example:
Data register = qudit, program register = 2 qudits

$$\boldsymbol{U}_k \equiv \boldsymbol{U}^{(mn)} = \sum_{s=0}^{D-1} \exp\left(-\frac{2\pi i s m}{N}\right) |s-n\rangle\langle s|$$

$$|\psi_k\rangle \equiv |\Xi_{mn}\rangle = \frac{1}{\sqrt{D}} \sum_{s=0}^{D-1} \exp\left(-\frac{2\pi i s m}{N}\right) |s\rangle |s-n\rangle$$



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