

Annual Lecture

Professor Vlatko Vedral

Risk and Reality

Universe as information

- The Universe is fundamentally made up of bits of information, not matter and energy
- The same information at the root of various physical, biological, computational and even economical and sociological phenomena
- Ultimately, information is quantum...
- Reality emerges through an interplay between random and deterministic (“conjectures and refutations”)

Physics as information

- Physics all about predictions
- Information about the system crucial
- How much information?
- Speed of processing...

Laplace: Gimme all positions and velocities of all particles and I will tell you the future exactly.

Maxwell: Gimme all positions and velocities of all particles and I will violate the Second Law.

Catalogue of information

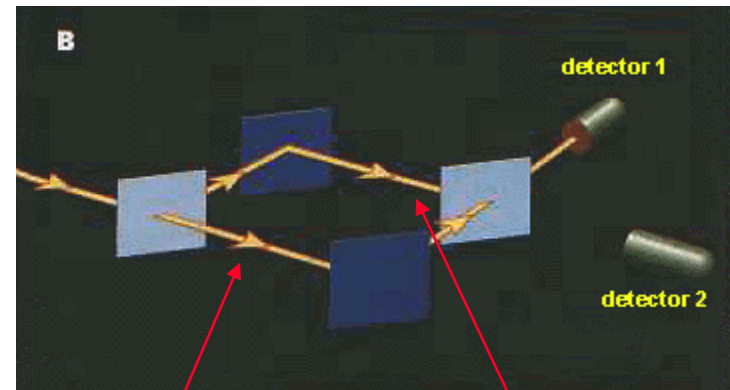
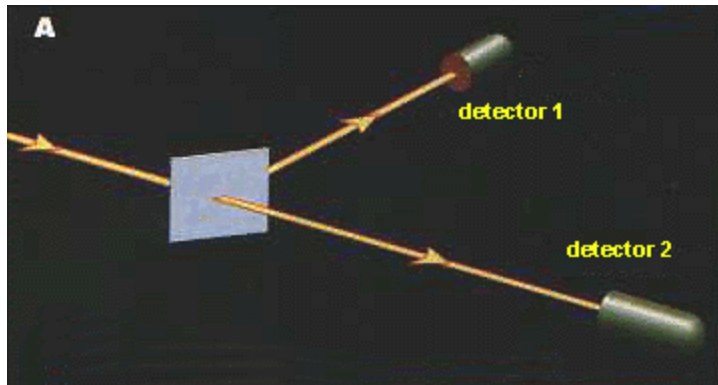
- States of physical systems are betting portfolios
- Laws of physics: how does the portfolio change in time?

$$\begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} 0 \\ 1 \end{pmatrix}$$



Quantum betting: Two things at once



Which path is taken?

SUPERPOSITION



BOTH

Superposition principle

Suppose we want to encode a bit of information into a state of photon after the beam-splitter.

Classical bit can be in only two possible states 0 or 1; qubit can be in any superposition as above.

$$|\psi\rangle = a \begin{pmatrix} 1 \\ 0 \end{pmatrix} + b \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \begin{pmatrix} a \\ b \end{pmatrix}$$

Quantifying information

All we need is probability for something, p .

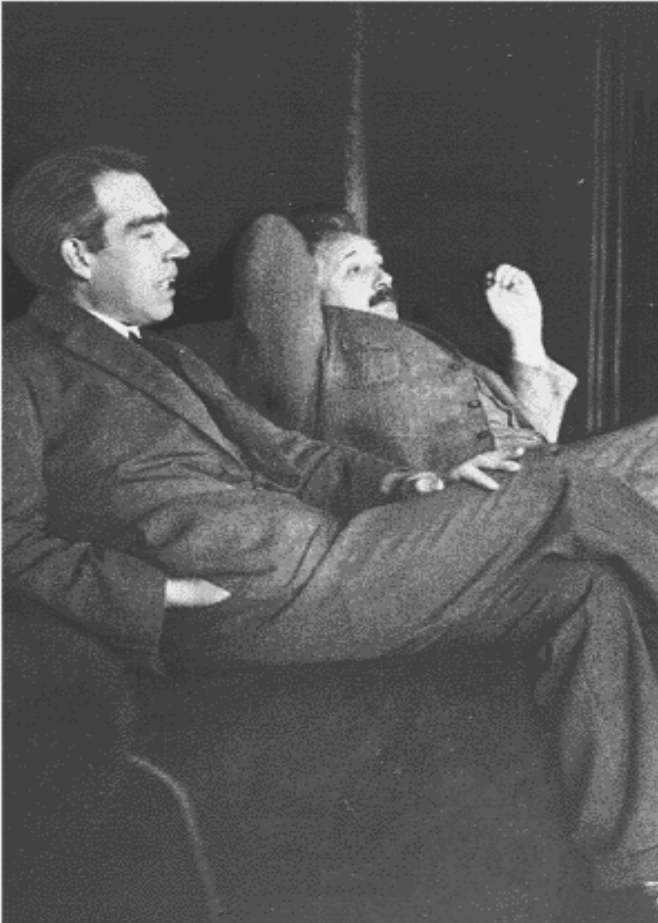
$$I = \log 1/p$$

Construct everything from probabilistic events.

Kelly's betting:

$$W = 2^{n(1-I)}$$

Bohr-Einstein Dialog



Einstein:

„Out there is this huge world, which exists independently of us human beings and which stands before us like a great, eternal riddle, at least partially accessible to our inspection.“

Bohr:

„There is no quantum world. There is only an abstract quantum physical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can *say* about nature.“

Bohr and Einstein in the twenties, at the house of Paul Ehrenfest.

Classical versus quantum physics

- Classical physics describes large (slow) objects.
- Quantum physics was introduced to describe small objects. (but we know also applies to large ones!)
- Main difference?
- Schrödinger: Entanglement is the key difference!

Entanglement



E.Schrödinger, ``Die gegenwärtige Situation in der Quantenmechanik", Naturwissenschaften, **23**, 807-812 (1935).

$$|\Psi_{ab}\rangle \neq |\Psi_a\rangle \otimes |\Psi_b\rangle$$

Information about "a" and "b" is not the same as information about "a" and information about "b"!

Schrödinger's cat



Schrödinger's cat



Dead...

Schrödinger's cat



... or alive.

Schrödinger's cat



Dead... and alive.



Happy...and sad.

Not in the mind of God!

Einstein: “Spooky Action at a Distance.”

$$|\psi^-\rangle = |\uparrow\rangle|\downarrow\rangle - |\downarrow\rangle|\uparrow\rangle$$

$$|\psi^-\rangle = |\rightarrow\rangle|\leftarrow\rangle - |\leftarrow\rangle|\rightarrow\rangle$$

Measure one of the spins – know immediately the value of the other.

Key conclusion: the value of spin does not exist before it is measured! Randomness and breakaway from causality.

Physics as a game of cards

Have:



Want:



Two rules:

1. You can only ask for a card if you have one of the same kind;
2. If asked and you have this type of card you must give it up.

Amazing conclusion: DON'T NEED CARDS TO PLAY THE GAME!

Important Question:

Can macroscopic entanglement exist under high temperature and other external conditions?

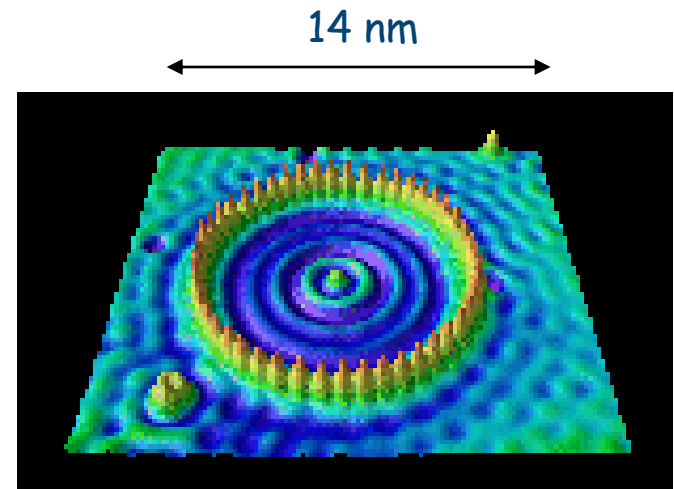
Books: “The God Effect”, B. Clegg



V.Vedral, “Better than a perfect match” Nature, (2006)

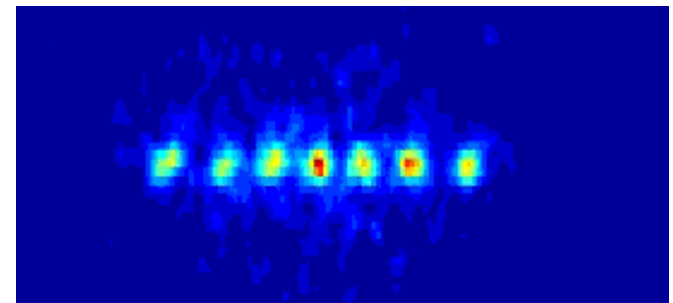
Viewing the quantum world

Electrons on the surface of a piece of copper are bound by 48 iron atoms (the spikes at the perimeter)



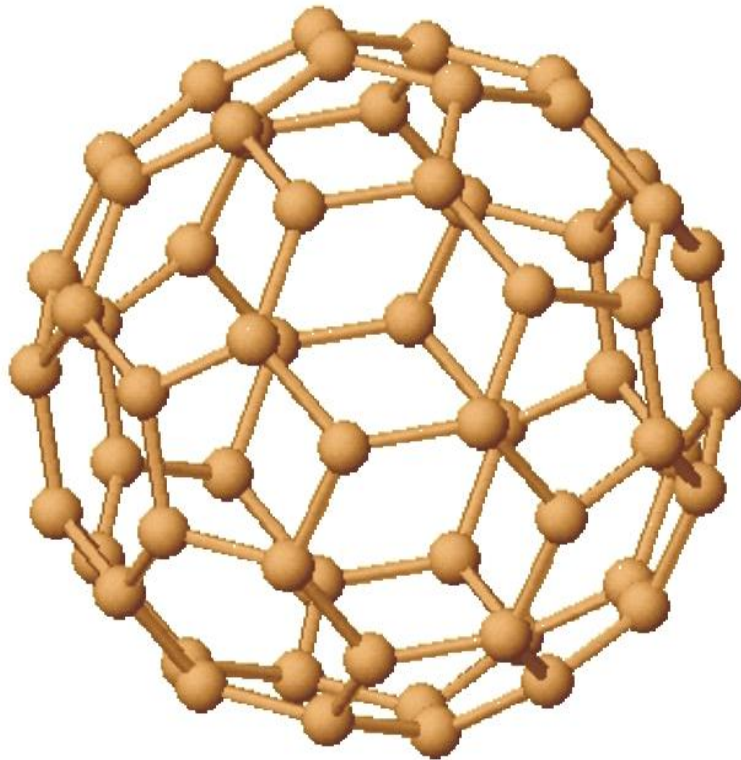
STM picture © IBM

Glowing and vibrating beryllium ions in a linear ion trap.



© Innsbruck University

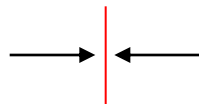
Fullerines (Bucky Balls)



$$\lambda_{\text{dB}} \approx 3 \times 10^{-12} \text{ m}$$

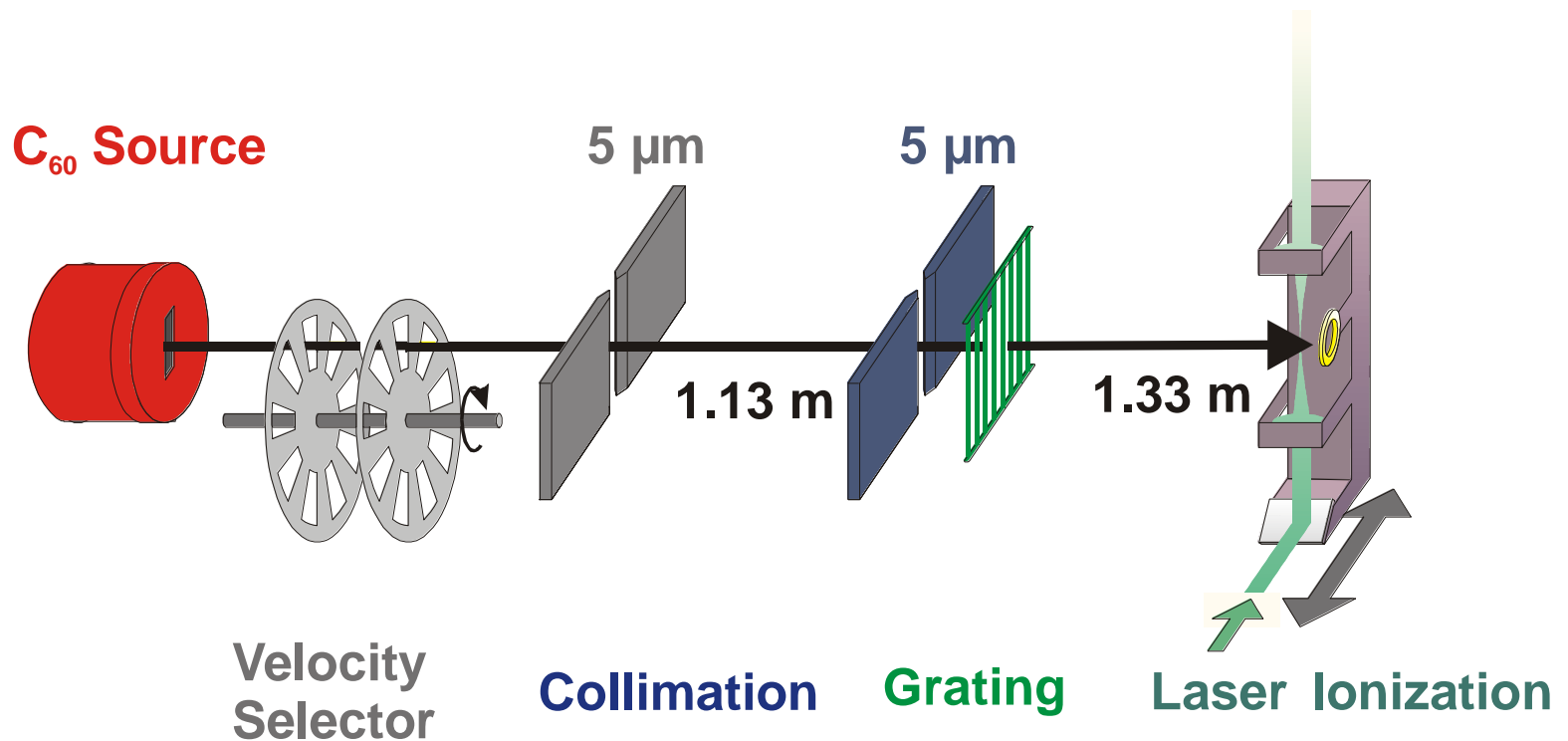
Diameter:
 $\text{C}_{60} \approx 10^{-9} \text{ m}$

$$\lambda_{\text{dB}} \ll D$$

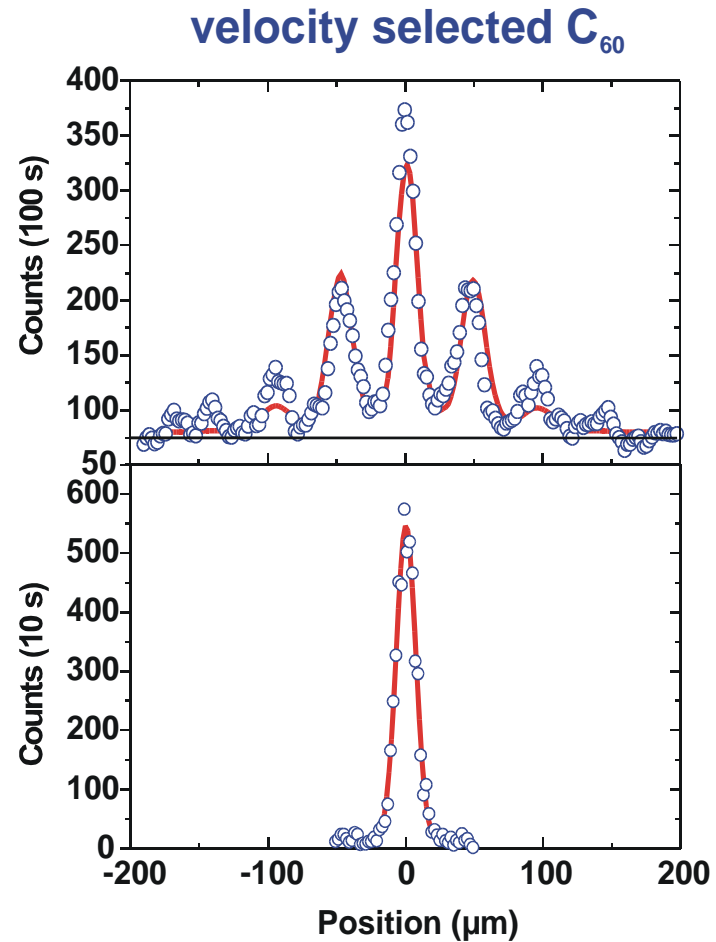

$$\lambda_{\text{dB}}$$

Diffraction of Fullerenes

Arndt *et al.*, 1999



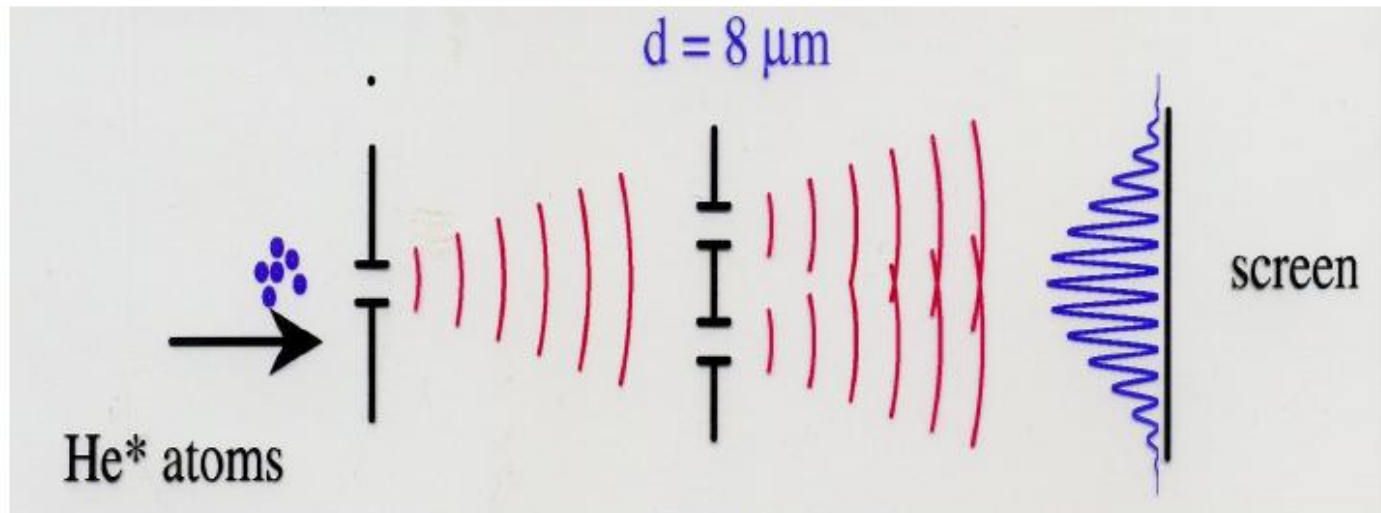
Fullerene interference



The wave nature of atoms

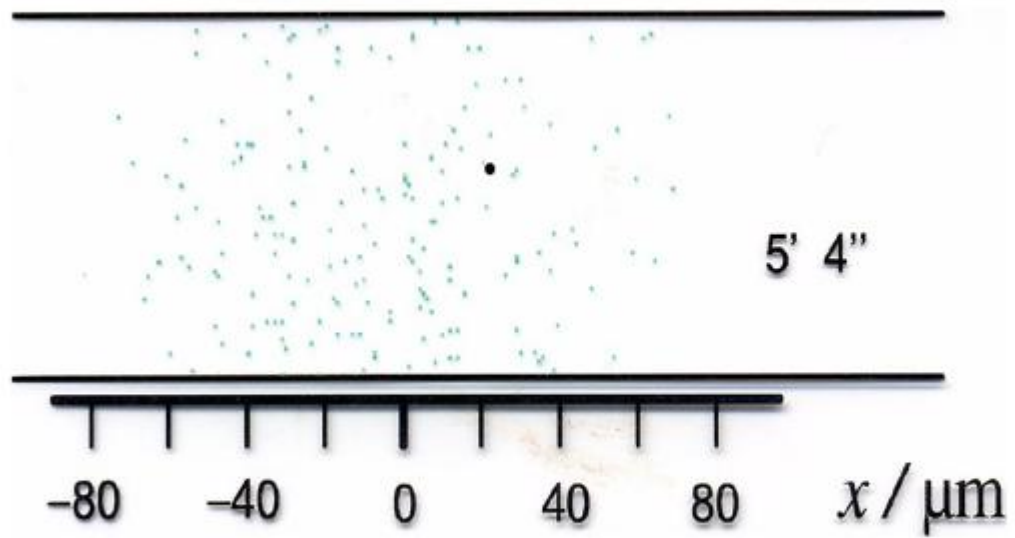
Young's double slit experiment:

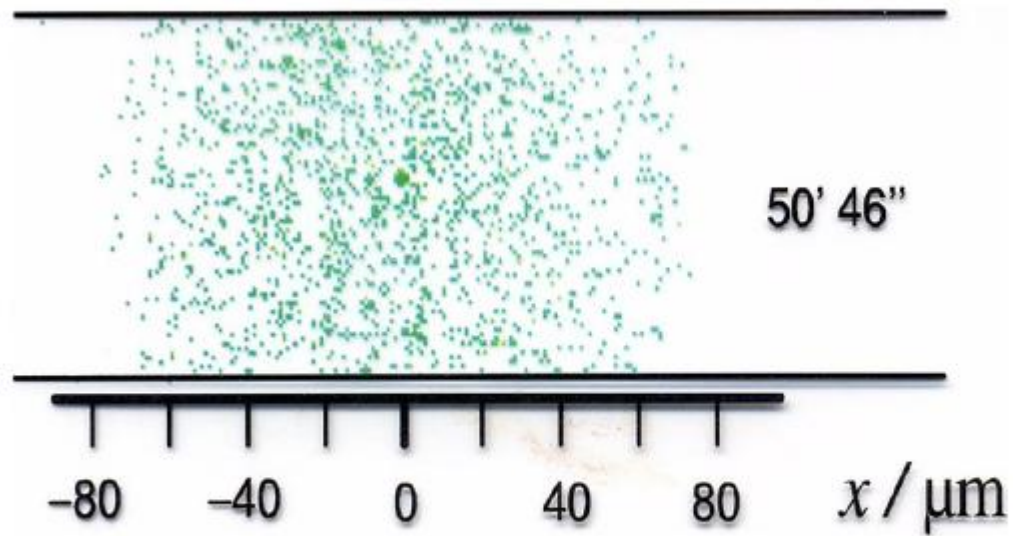
Early references for "matter optics": Davisson and Germer (1927), Estermann and Stern (1930), Boersch (1940), Möllenstedt and Düker (1955), Jönsson (1961, first double slit experiment, with electrons), Pritchard et al. (1988).
Cf. Physics World 2002/3

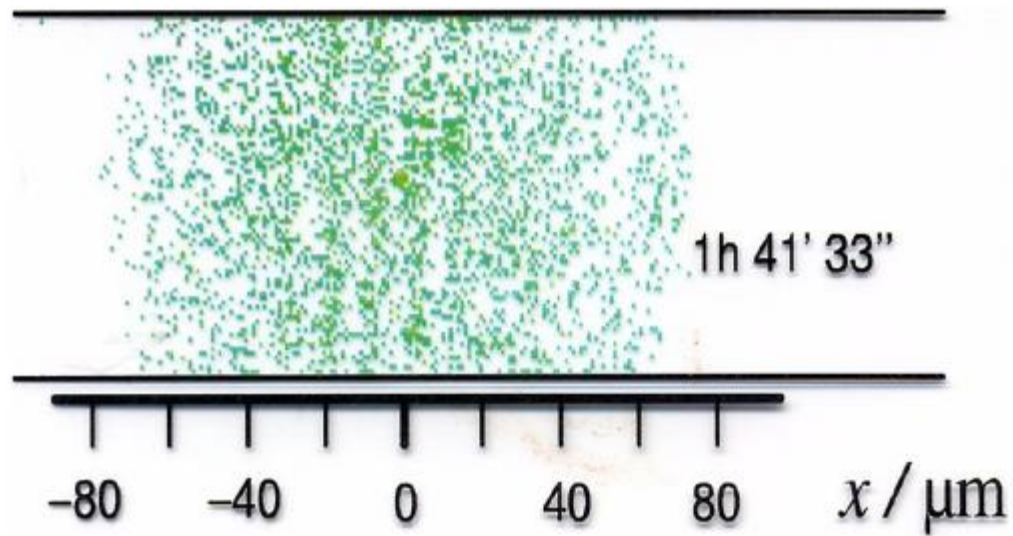


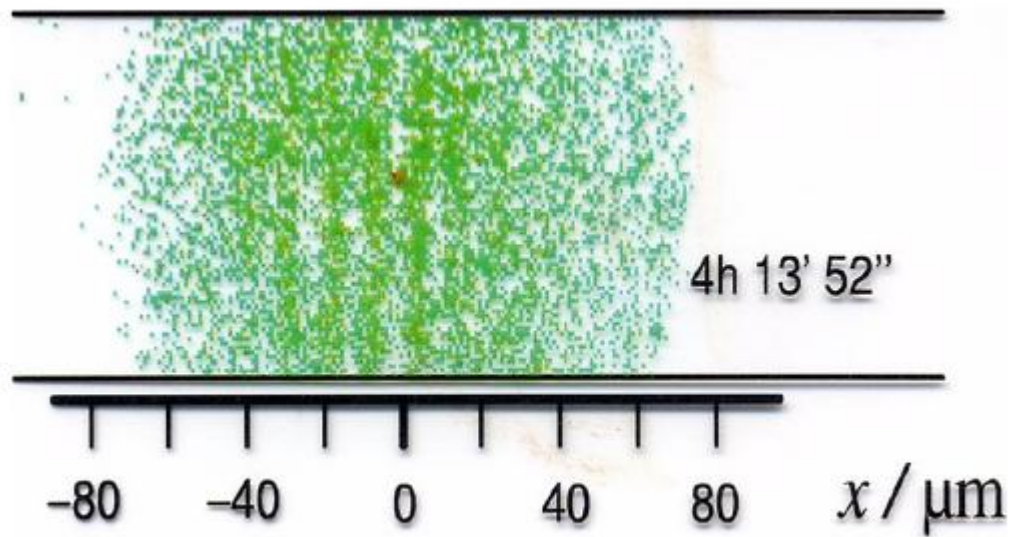
O. Carnal, J. Mlynek, PRL **66**, 2689 (1991)

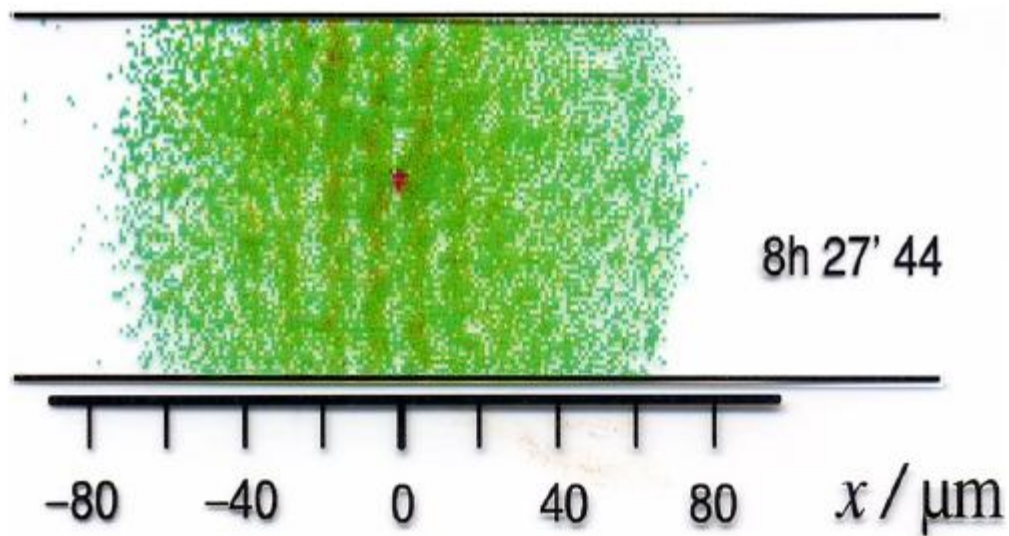
$$\lambda_{dB} = 46 \pm 5 \text{ pm}$$

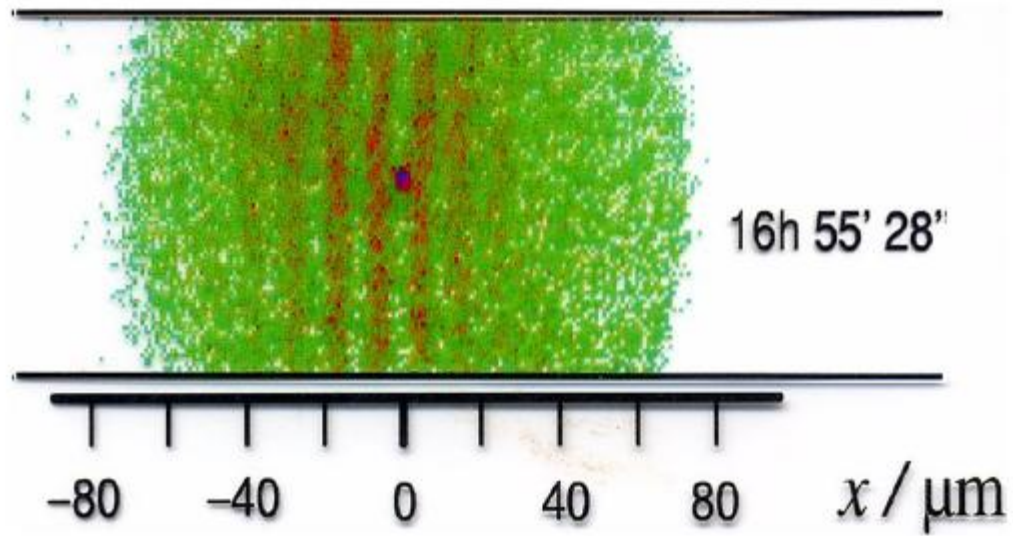


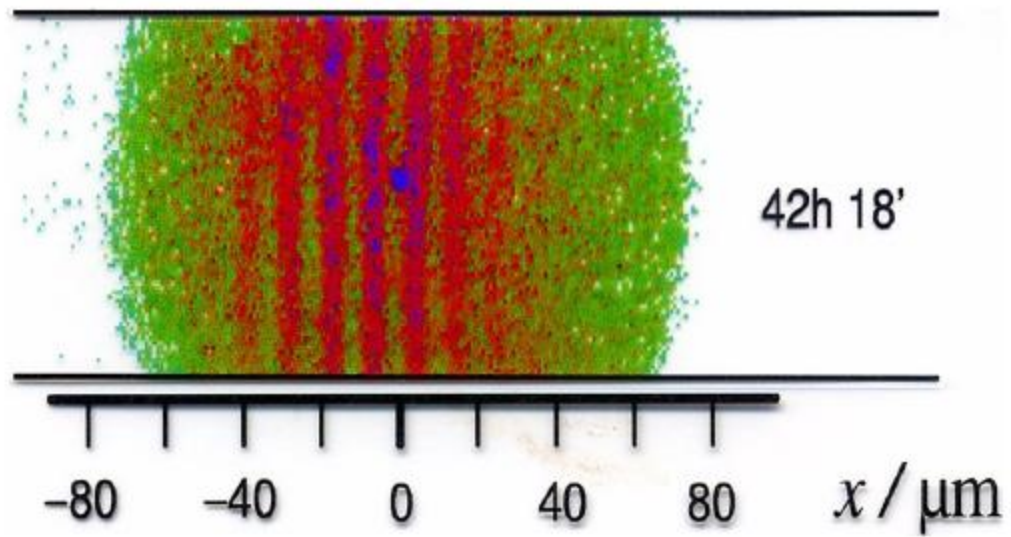




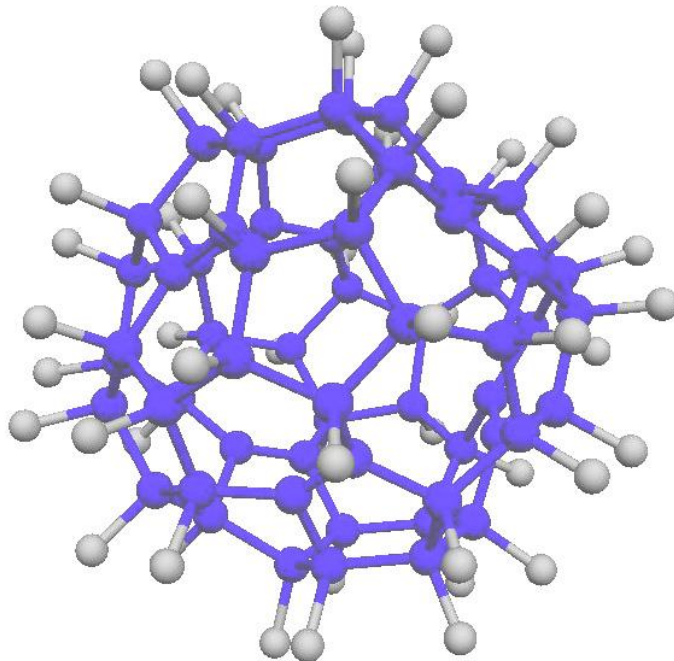






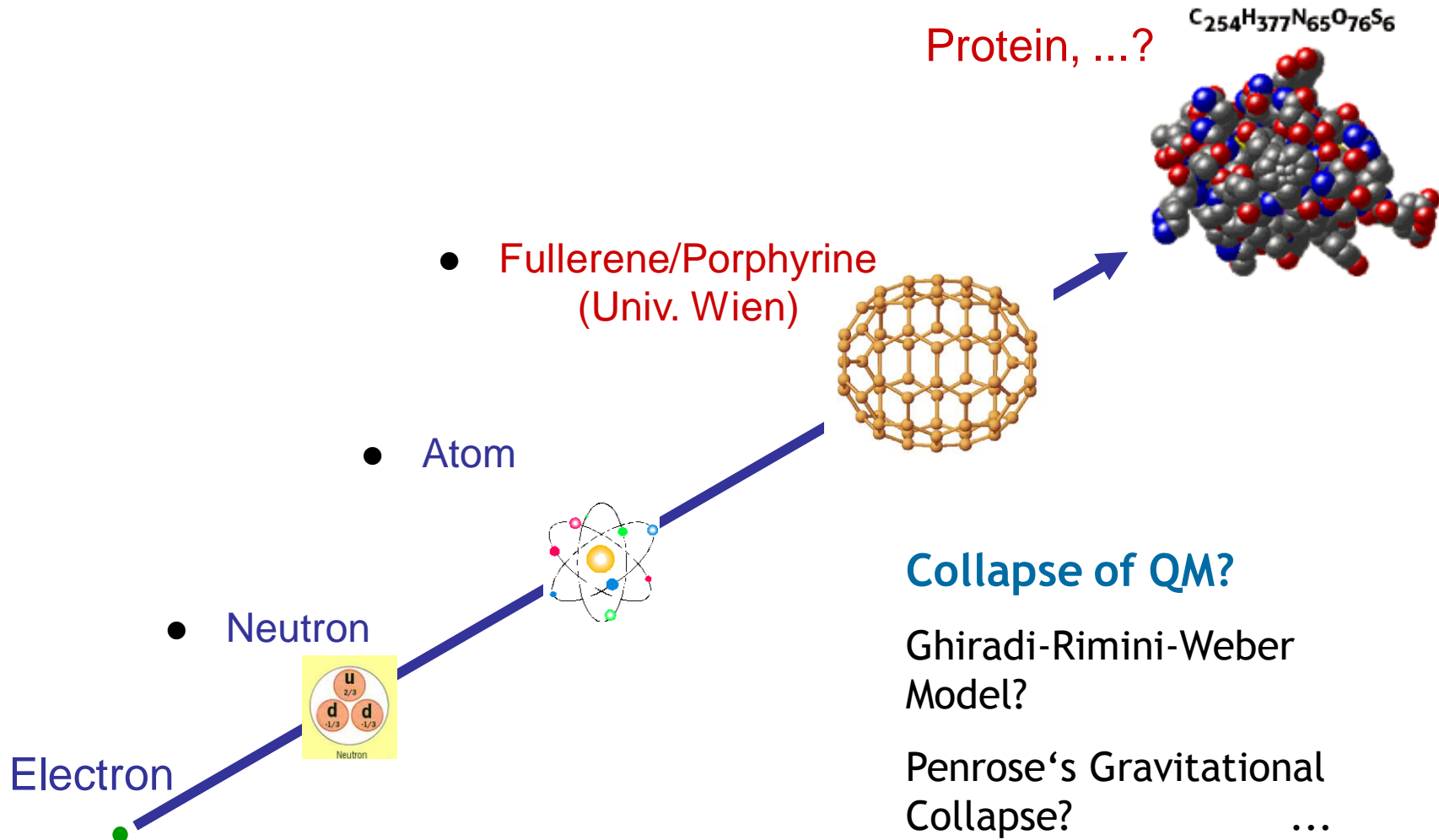


Current world record: (Vienna Group)



- C₆₀ F₄₈
- Mass: **1632** amu!
- **108** Atoms in a single object!

How far can we go?



Collapse of QM?

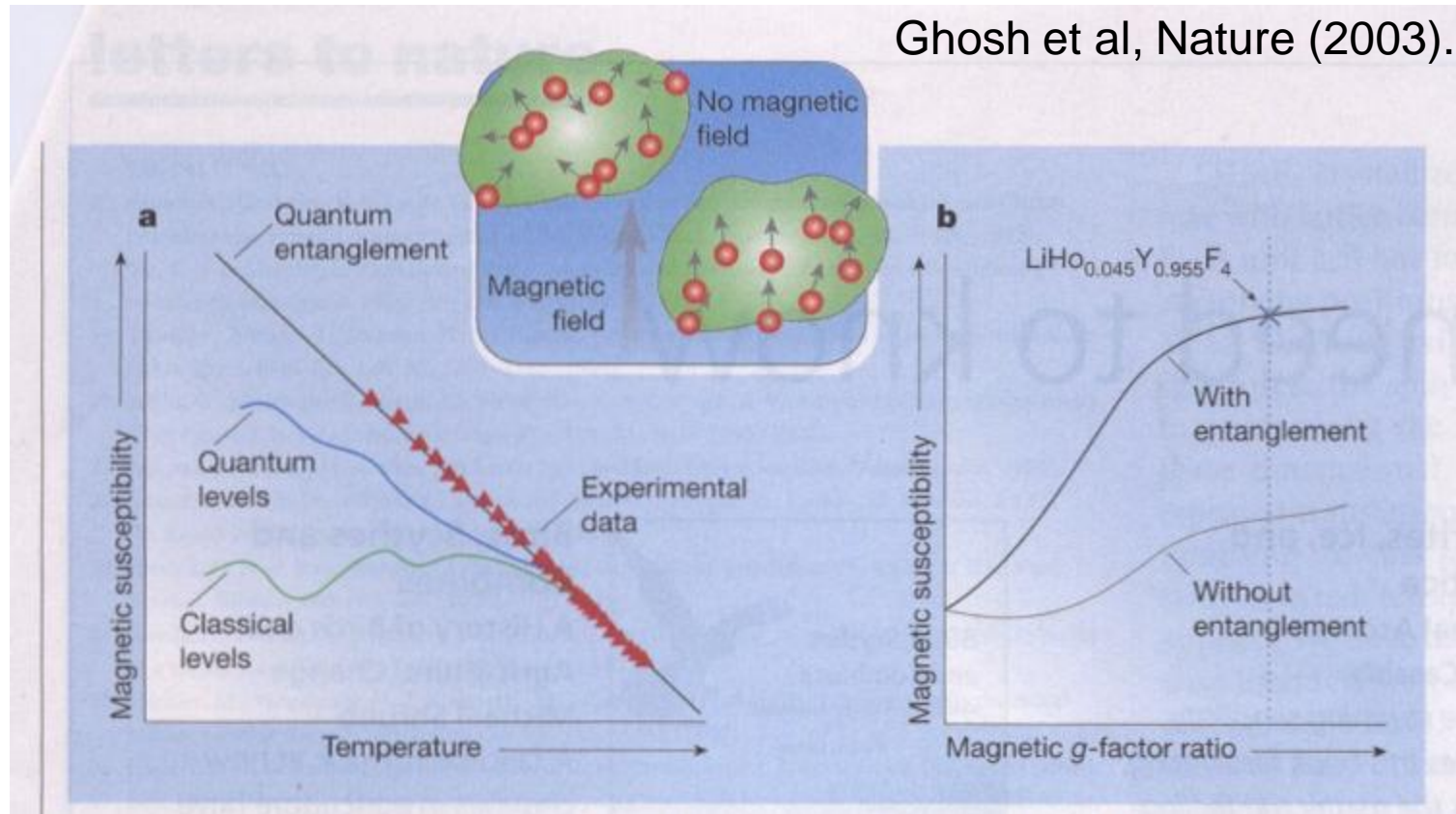
Ghirardi-Rimini-Weber Model?

Penrose's Gravitational Collapse?
...

Entanglement with a pinch of salt:

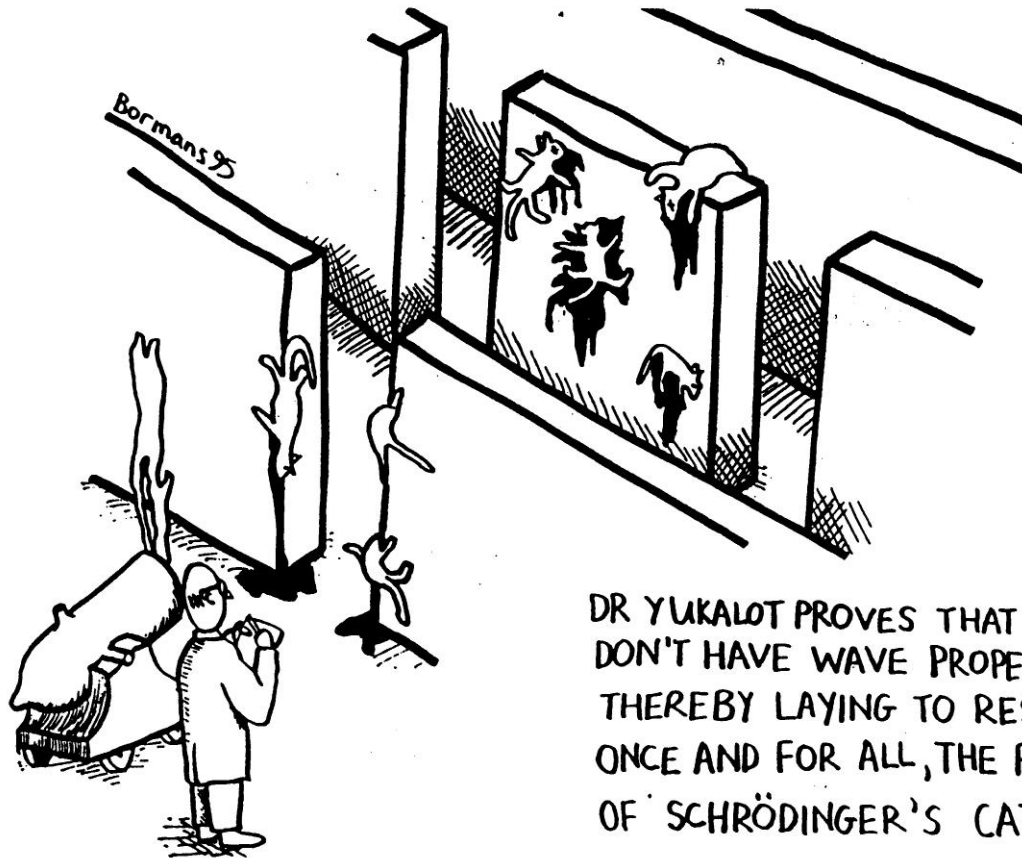


Ghosh et al, Nature (2003).



V.V., Nature (2003).

Macro interference?



DR YUKALOT PROVES THAT CATS
DON'T HAVE WAVE PROPERTIES,
THEREBY LAYING TO REST,
ONCE AND FOR ALL, THE PROBLEM
OF SCHRÖDINGER'S CAT.

Your computer



What's inside?



3-Year Warranty

High-performance Turbo-Cool® 300 ATX Power Supply with built-in line conditioning

Long-life Auxiliary Cooling Fan

Intel 440 BX AGP Set

Accepts 233-500 MHz Pentium® II or III (processor not included)

On-board Audio (optional)

3 DIMM Sockets (memory not included)

2 ISA, 4 PCI, 1 AGP Slots
66-100 MHz Bus Speed

Flash BIOS support for LS-120 and ZIP drives

Built-in Diagnostics

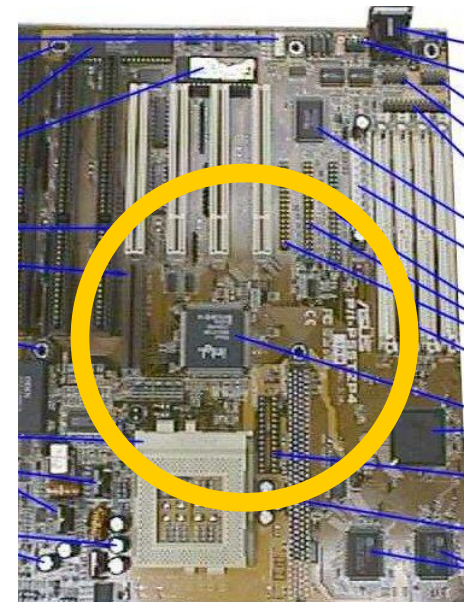
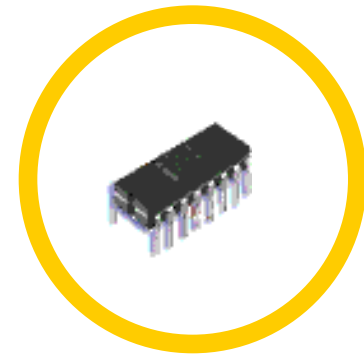
Quick Set-Up Instructions on inside panel

Rigid, easy-access Personal Mid-Tower Case (7.1"W x 17.1"H x 16.6"D)

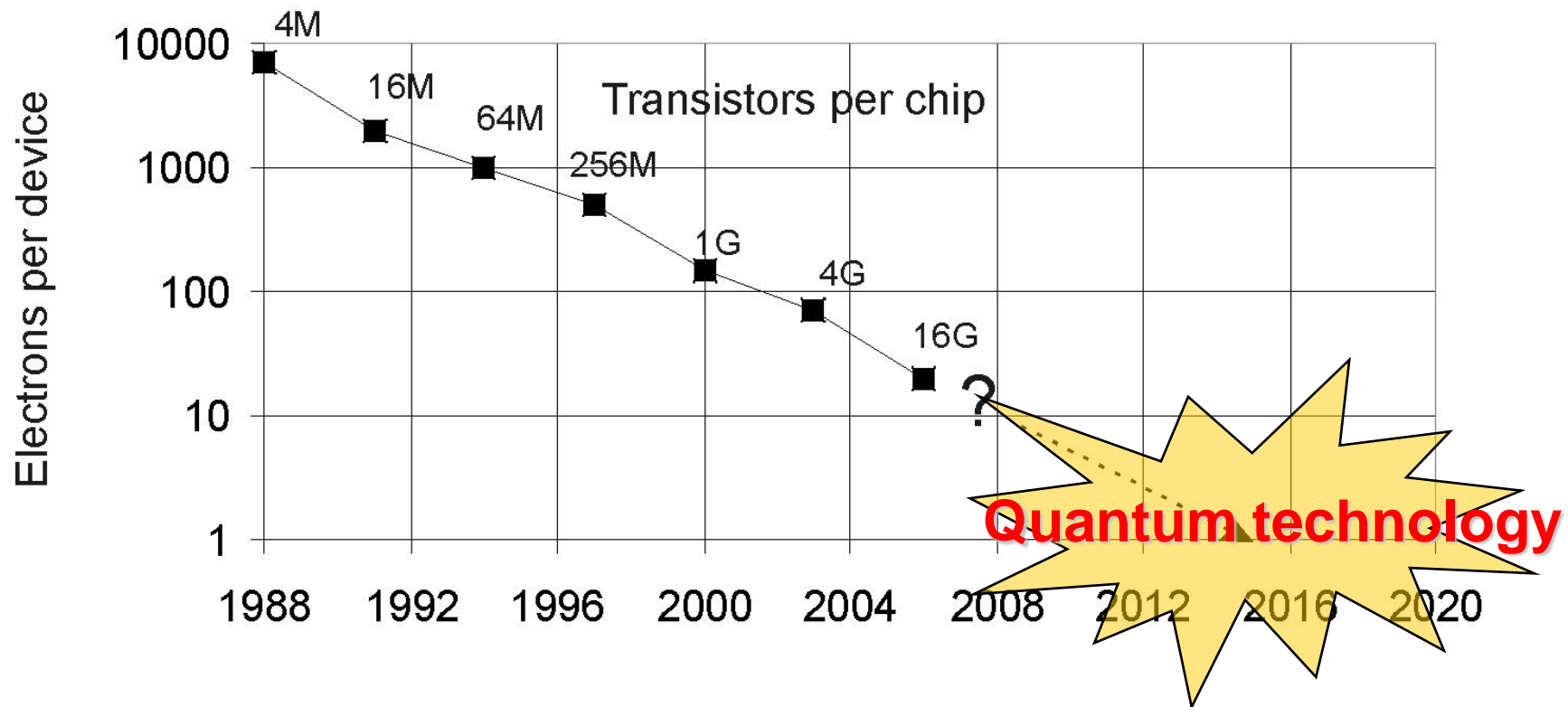
Auto-configuration (no jumpers to set)

6 Drive Bays (upgradable to 8 bays)

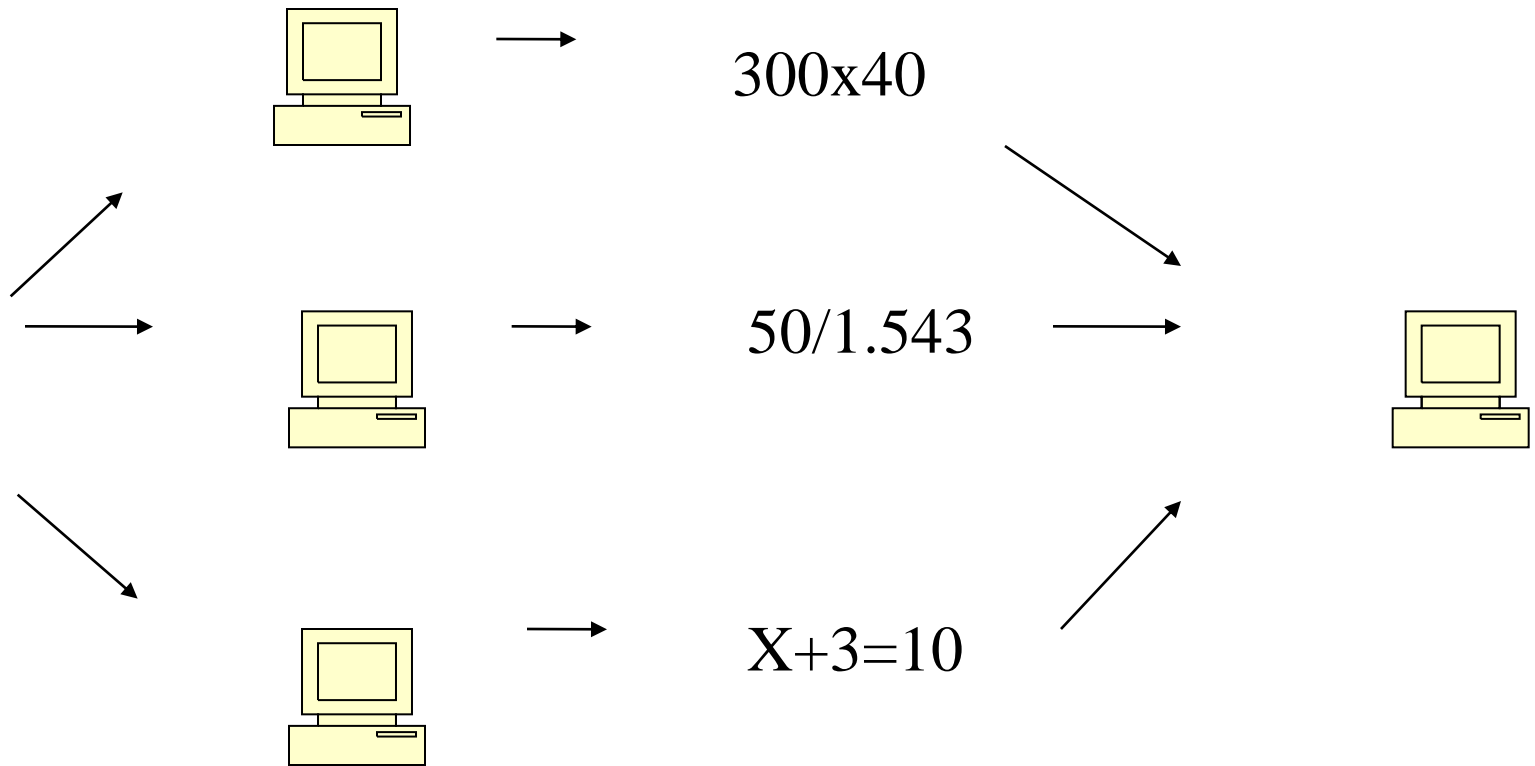
FC UL



Towards the quantum limit

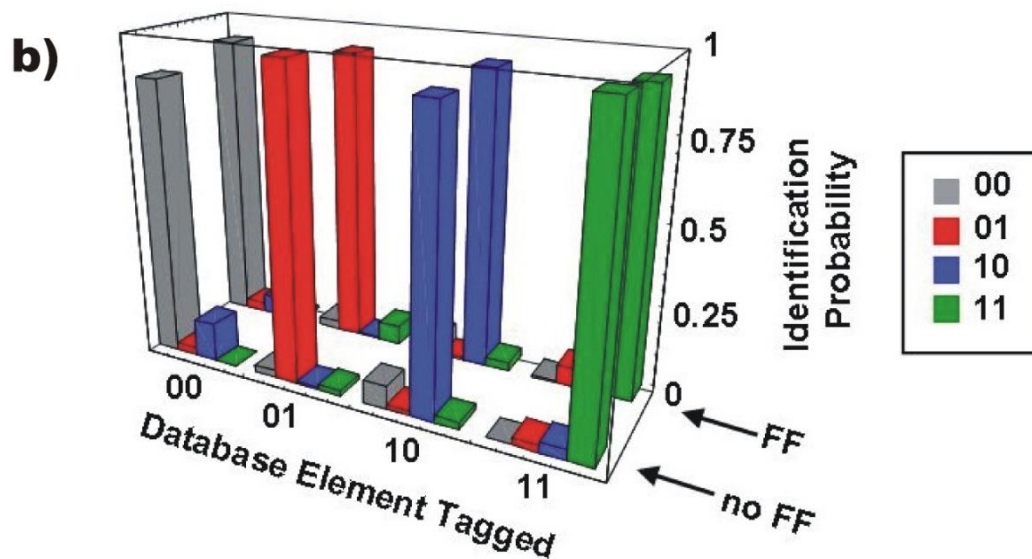
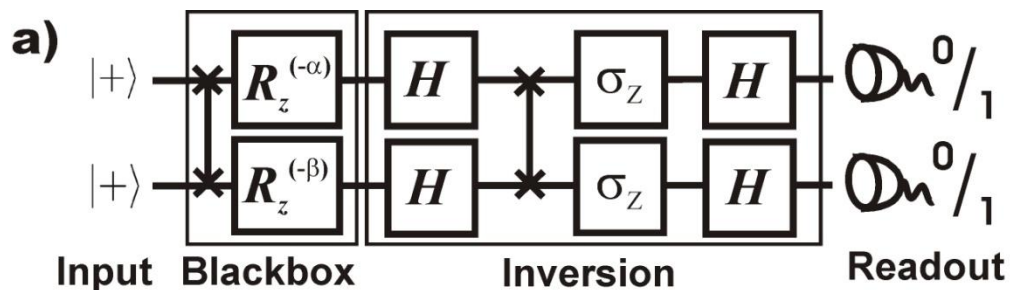


Quantum computers



Entanglement and Search

Vienna (2005), Nature March 2005.

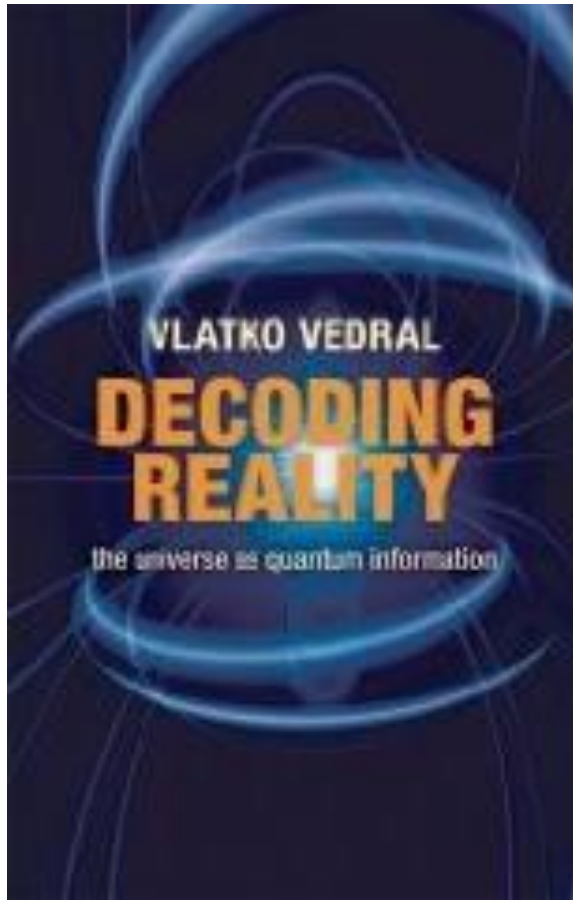


Interesting times...

In Italy for 30 years under the Borgias they had warfare, terror, murder, and bloodshed, but they produced Michelangelo, Leonardo da Vinci and the Renaissance. In Switzerland they had brotherly love—they had 500 years of democracy and peace, and what did that produce? The cuckoo clock.

Orson Wells – Third Man

Further reading



www.vlatkovedral.org