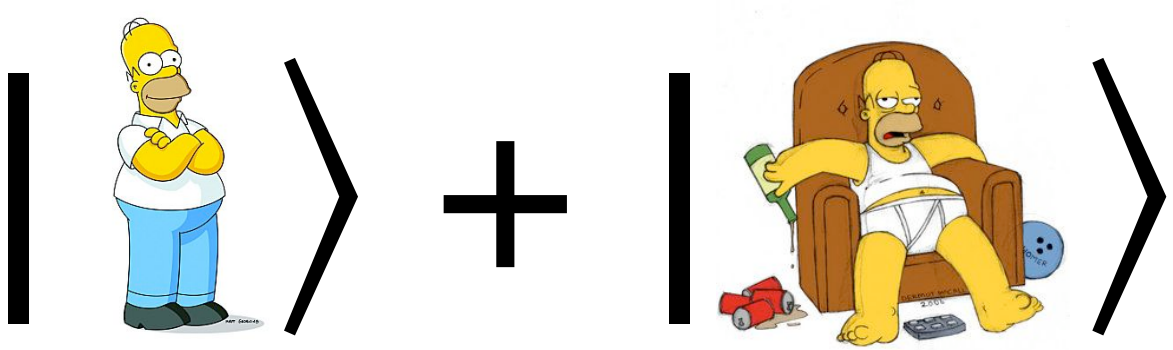
Quantum Strangeness In Unexpected Places

Aash Clerk

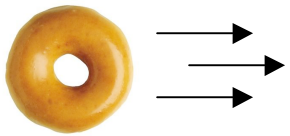


Schrodinger's Homer?

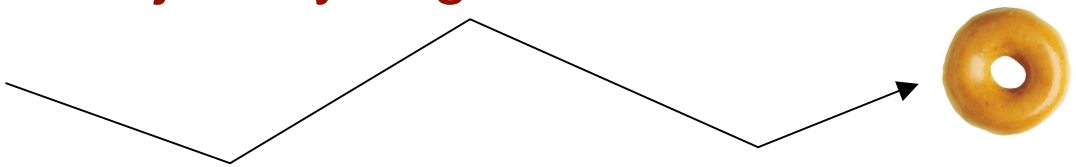
- Can we make "large" objects act in strange quantum ways?
- Quantum computers? When can I buy one?

Quantum Weirdness?

- Quantum mechanics
  - Theory describing the behaviour of very small stuff (atoms, electrons, etc.)
  - Incredibly well-tested; basis for various technologies (laser, transistor, etc.)
  - Tells us that small particles can behave in incredibly strange ways….
    - "the doughnut has a definite location and speed"



    - "the doughnut which just hit me followed some definite trajectory to get here"



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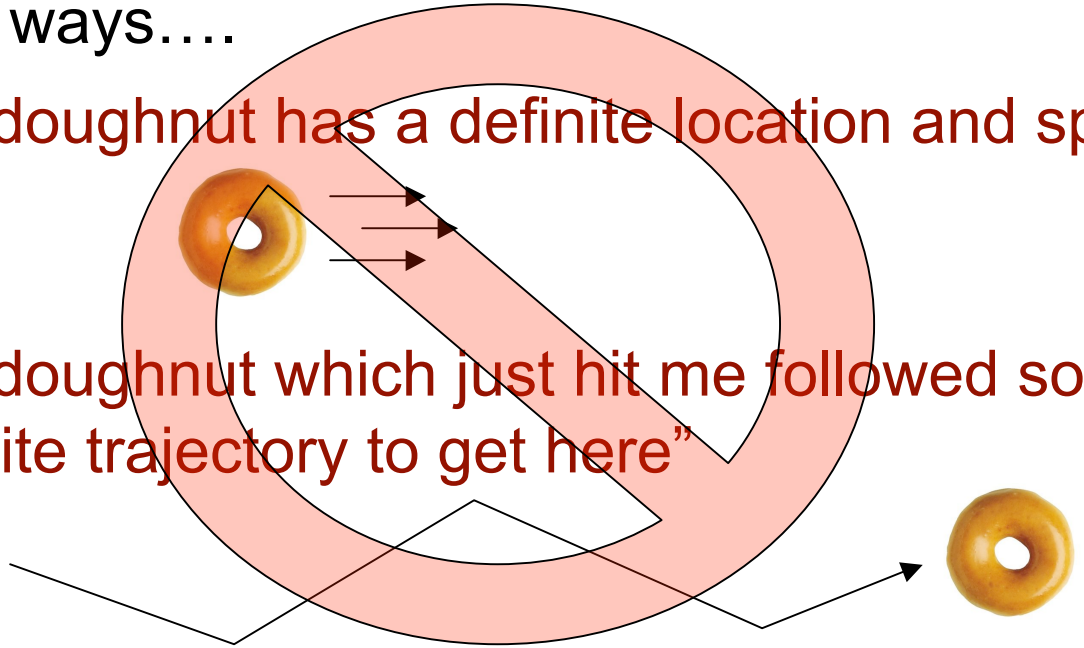
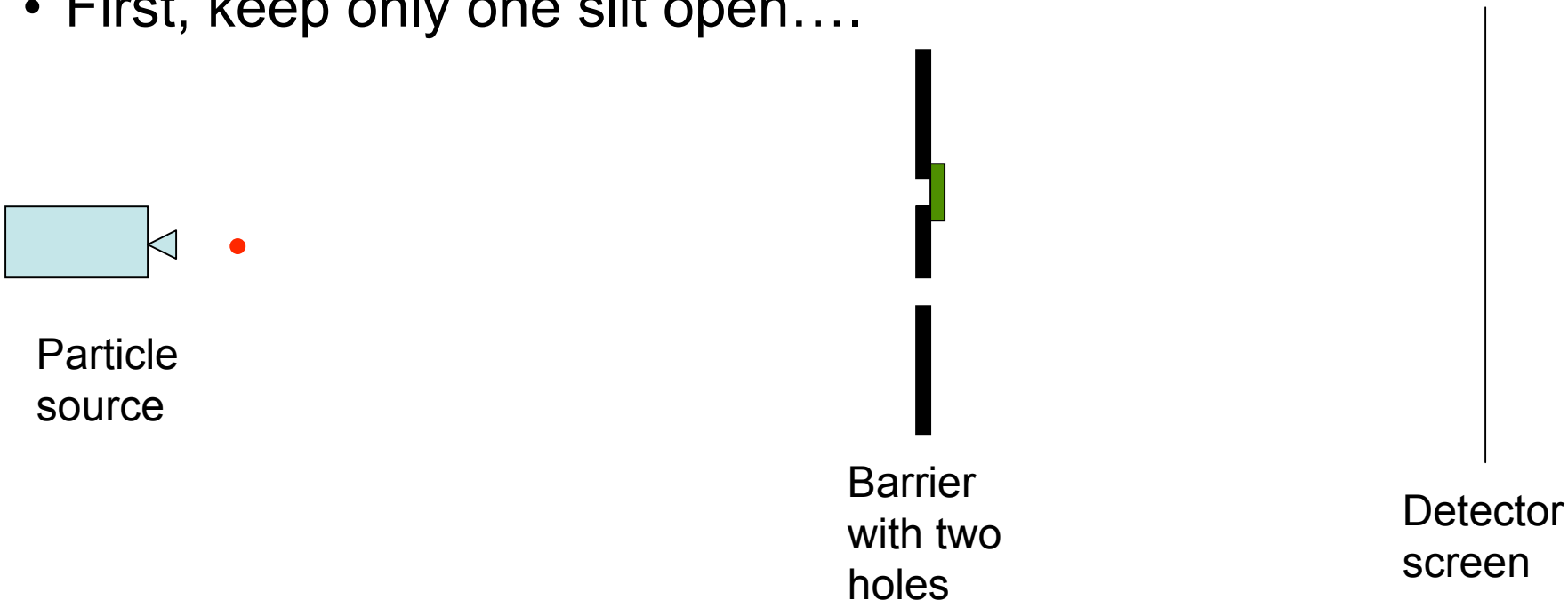


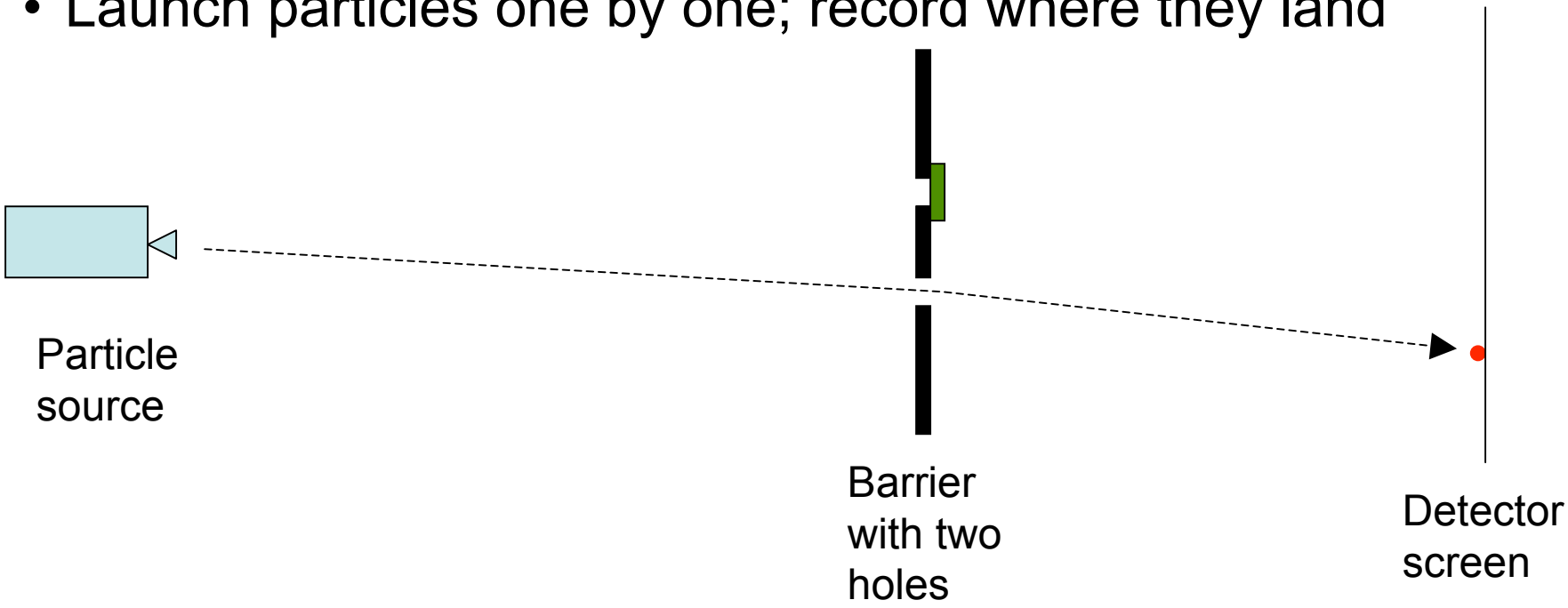
Two slit experiment: non-quantum

- First, keep only one slit open….



Two slit experiment: non-quantum

- Launch particles one by one; record where they land



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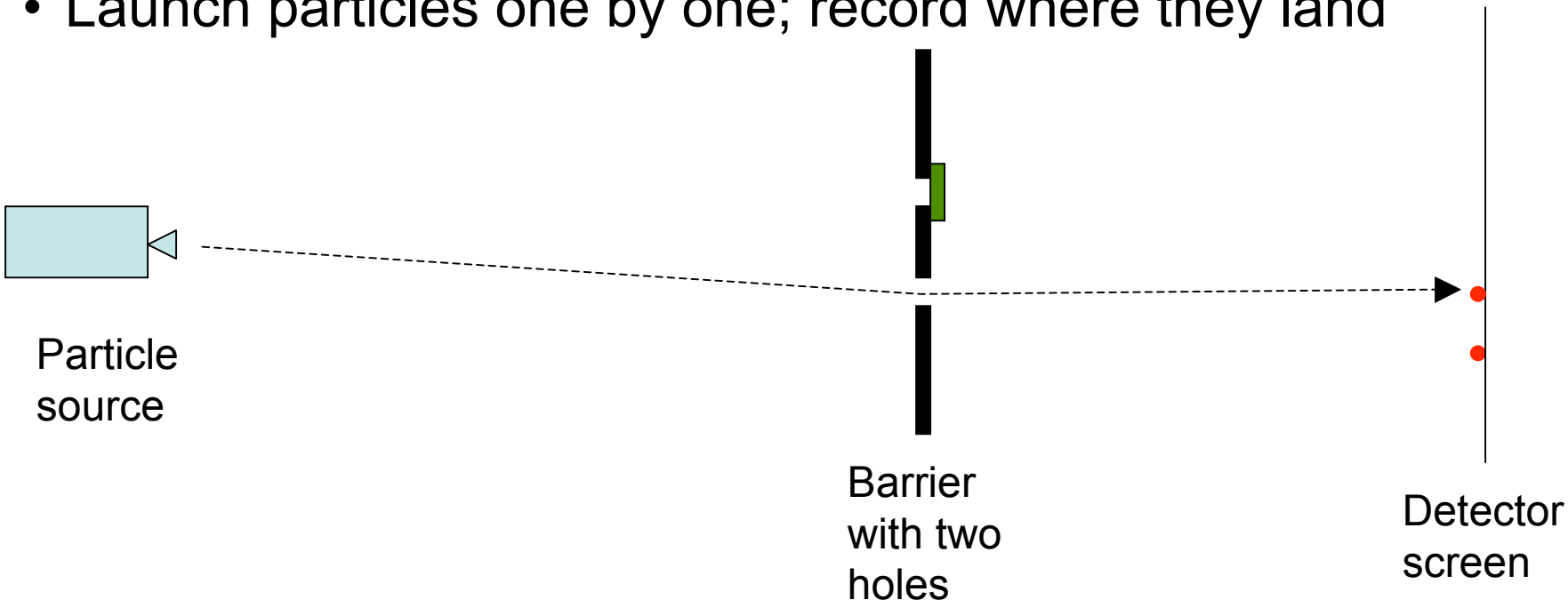
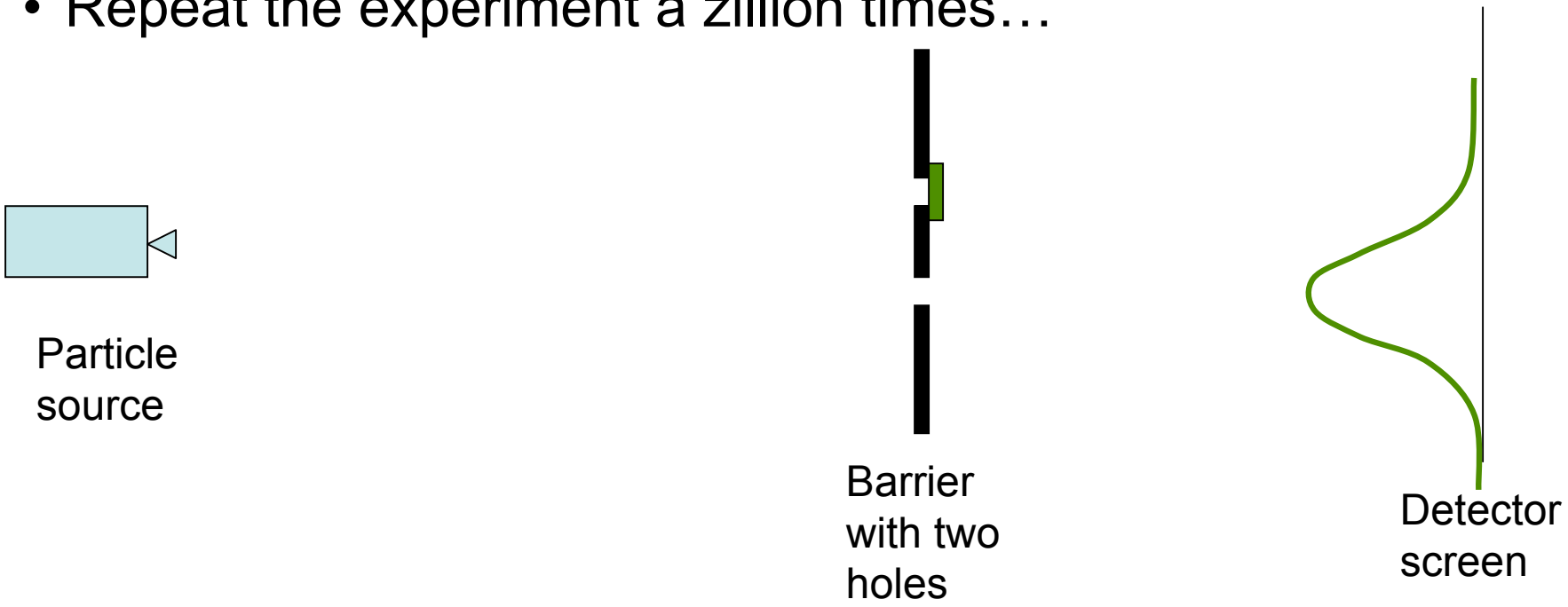


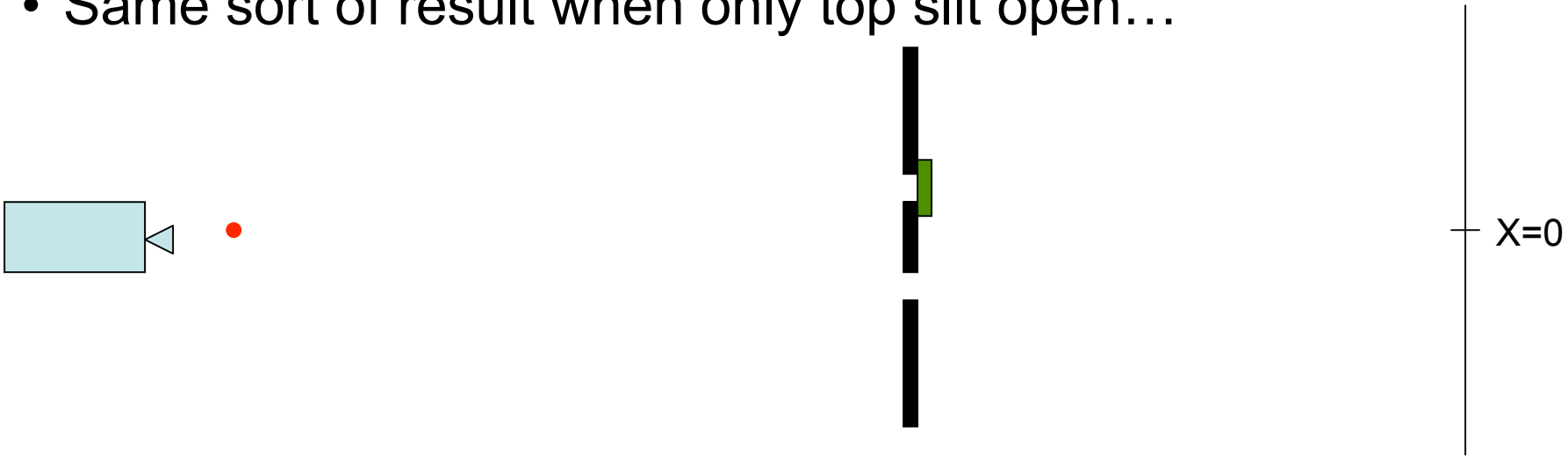
Two slit experiment: non-quantum

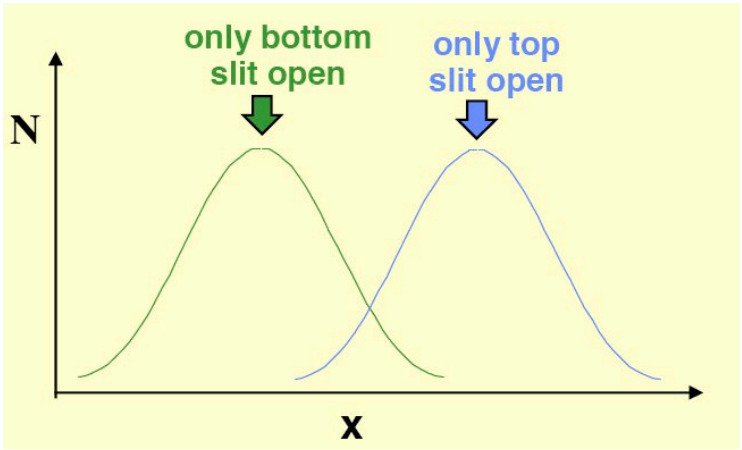
- Repeat the experiment a zillion times…



Two slit experiment: non-quantum

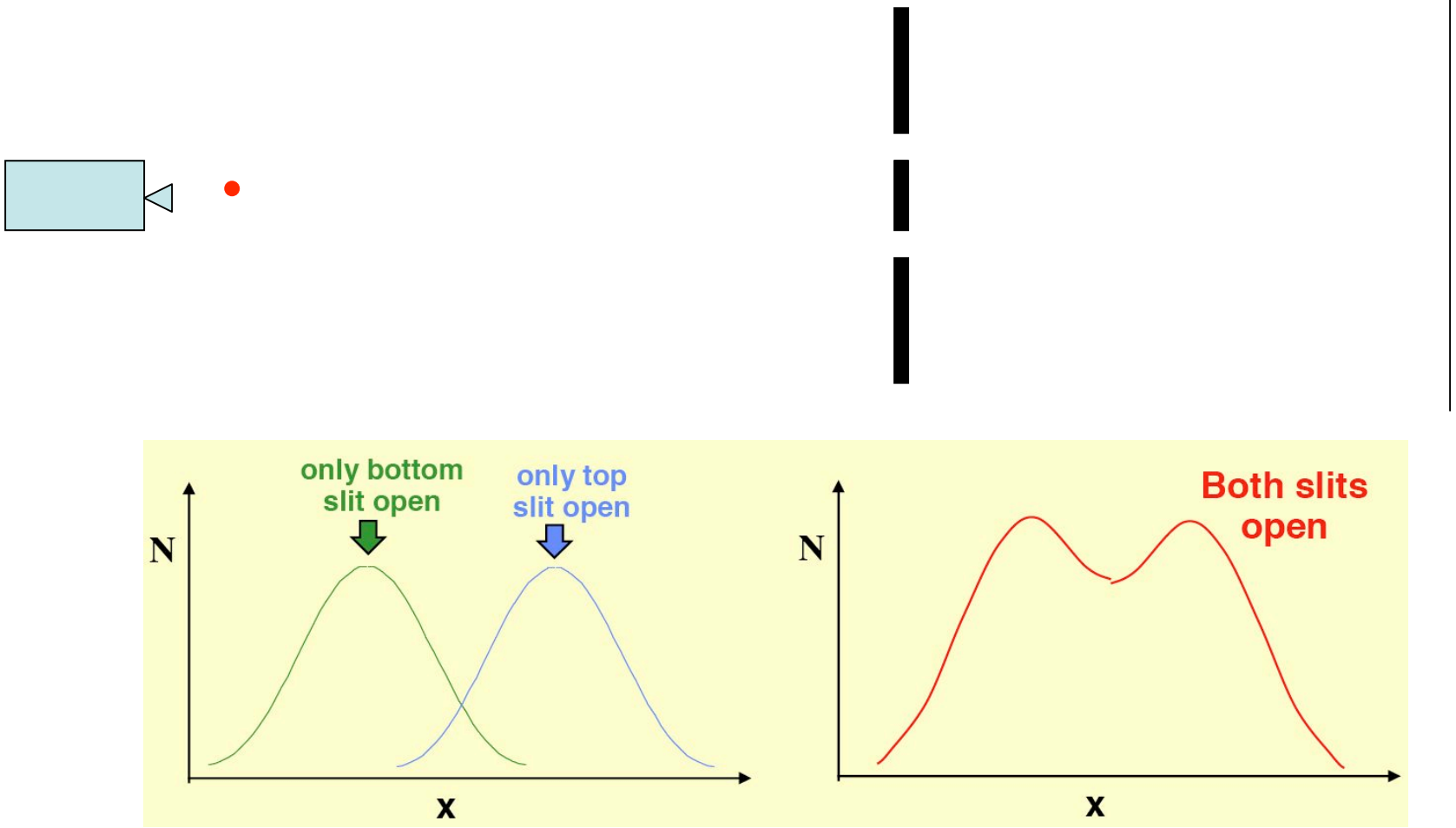
- Same sort of result when only top slit open…





Two slit experiment: non-quantum

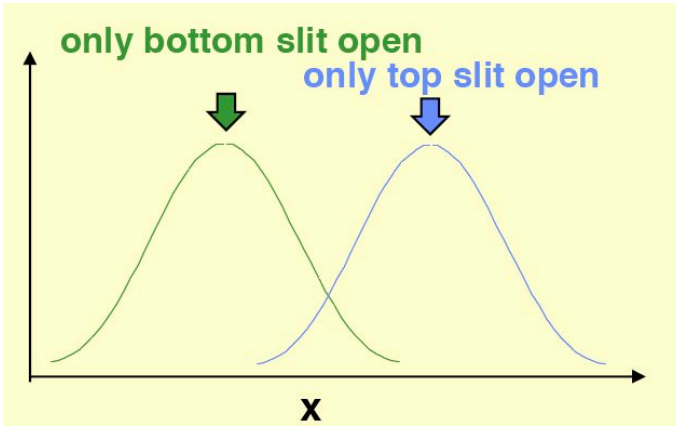
- Now, open both slits. For non-quantum particles, boring…



Each particle hitting the screen either came from the upper or the lower slit….

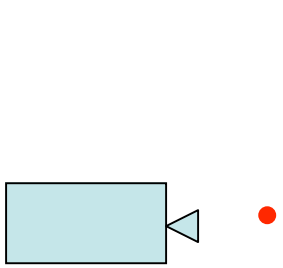
Quantum version

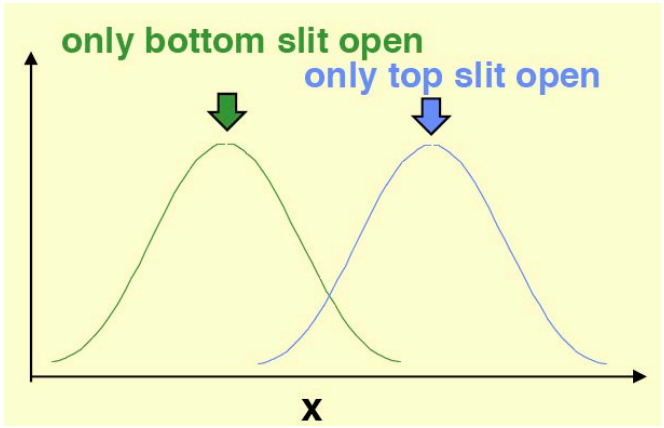
- Now for quantum particles: same if one slit open

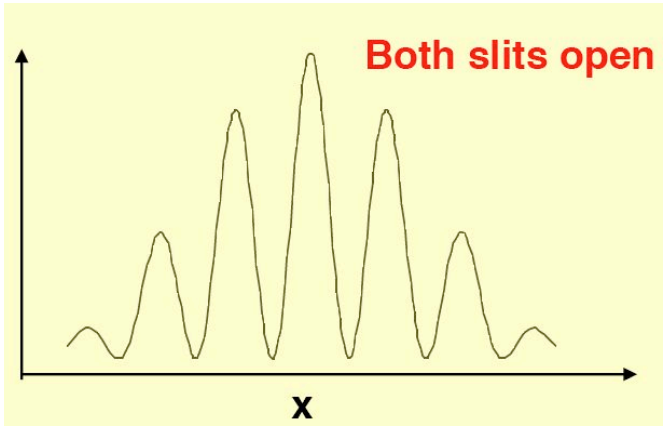


Quantum Version

- Both slits open? Craziness…

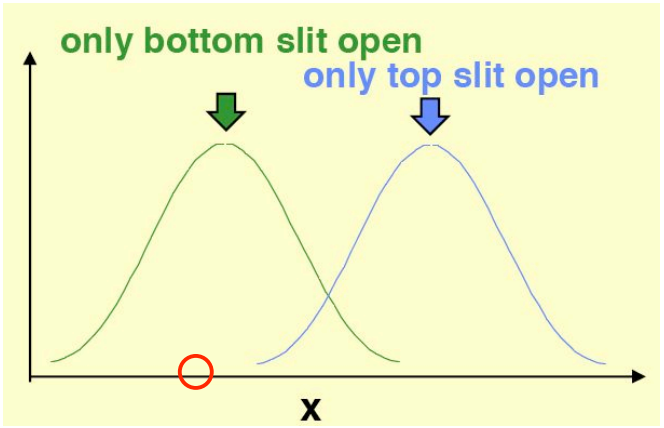


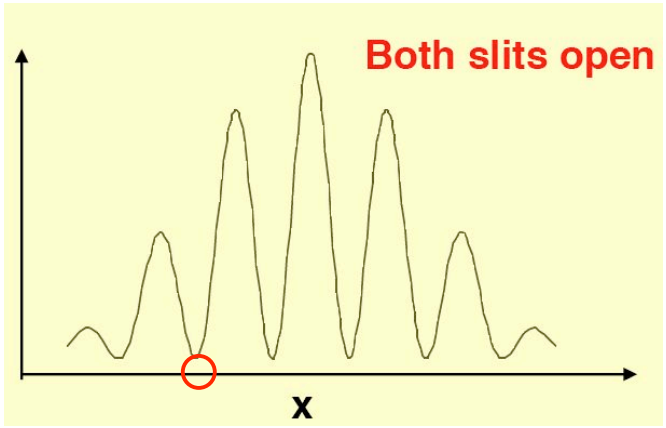




Quantum Version

- Two slit experiment, quantum particles:





Opening the second slit can **reduce** the number of particles that make it to a given point on the screen!

Quantum Version

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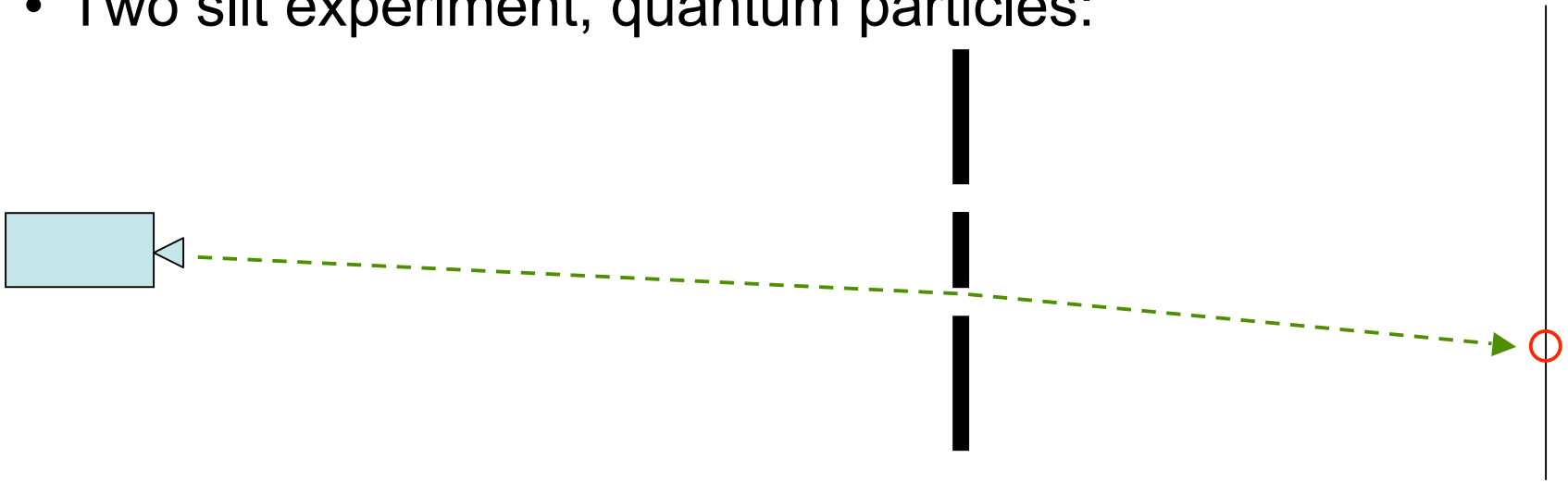

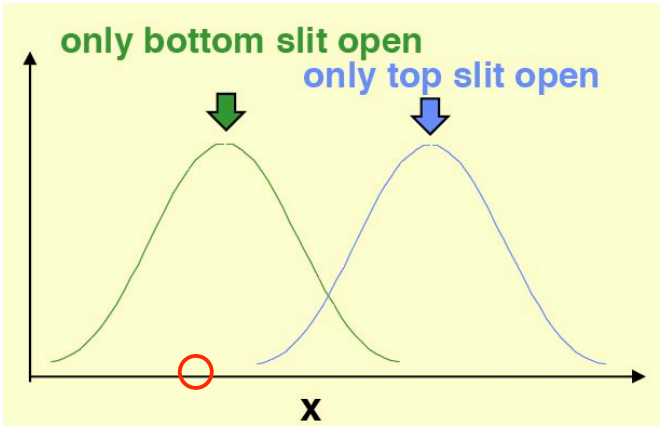

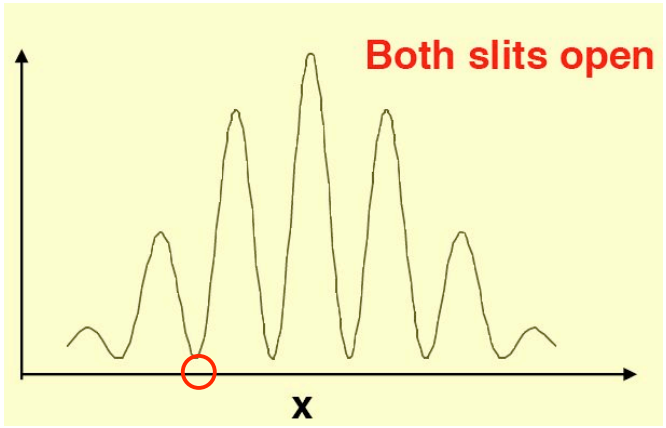

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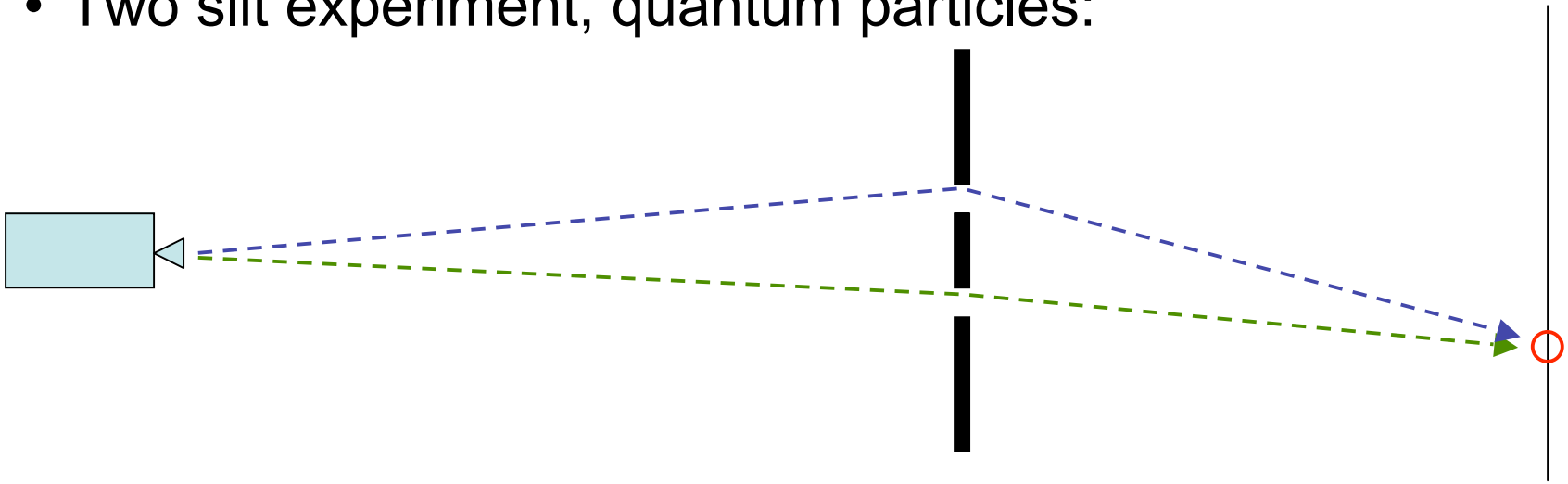
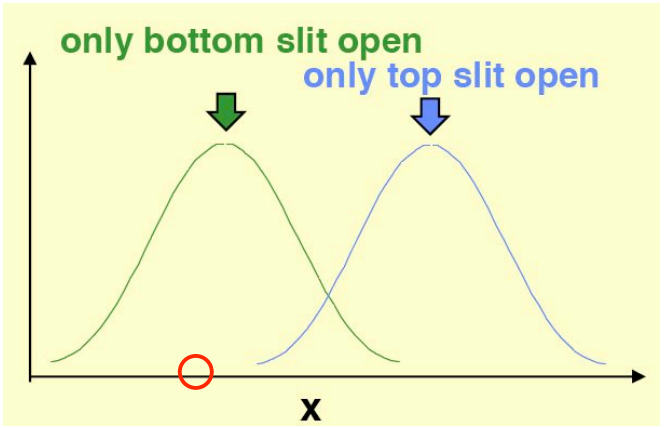
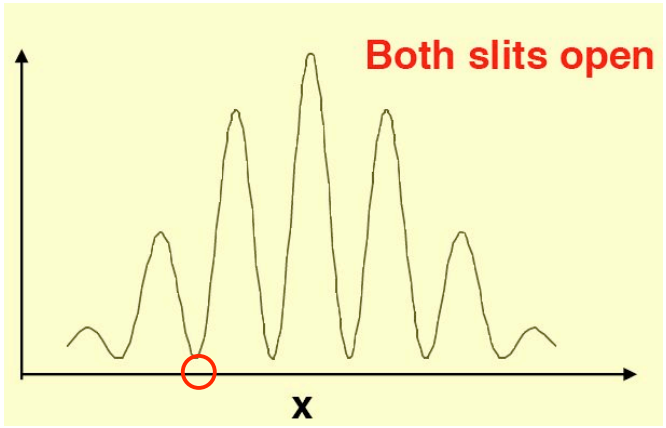


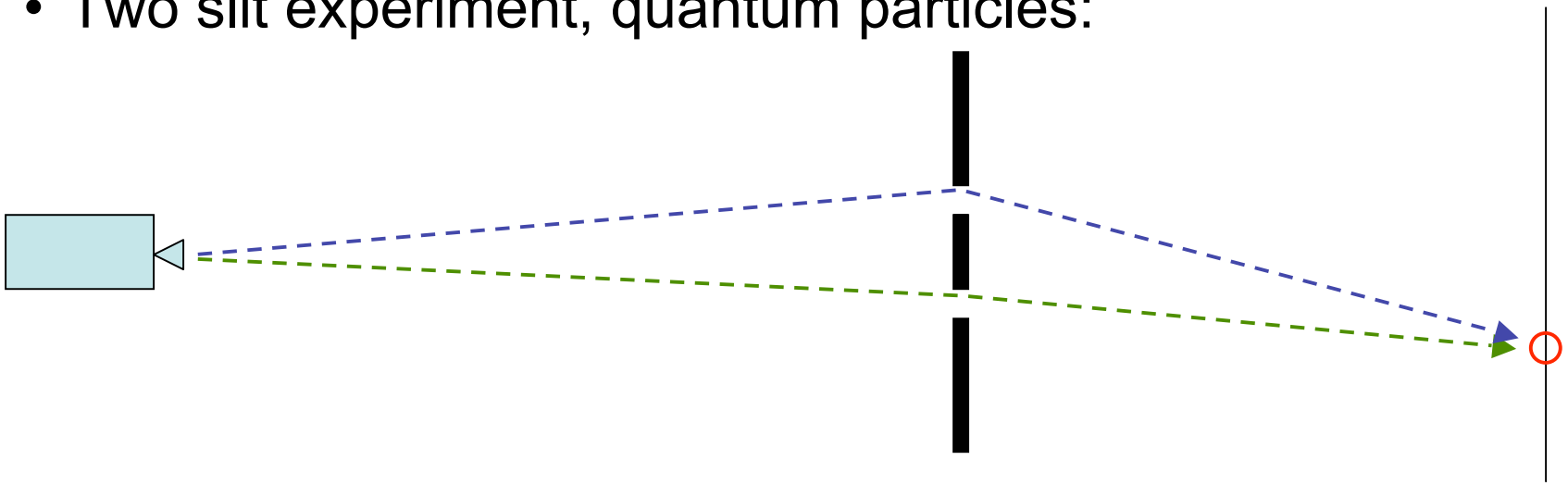


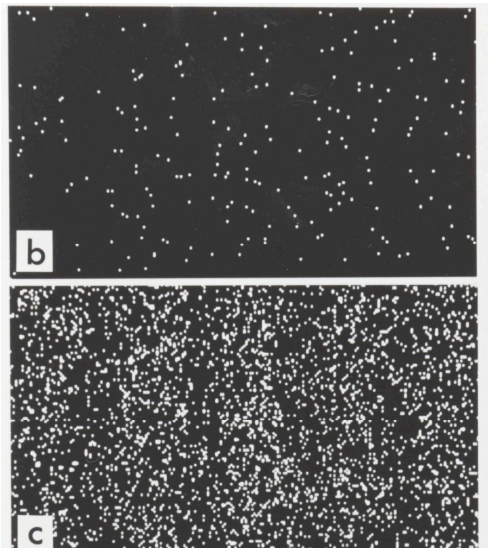


Opening the second slit can **reduce** the number of particles that make it to a given point on the screen!

Actual Experiment?

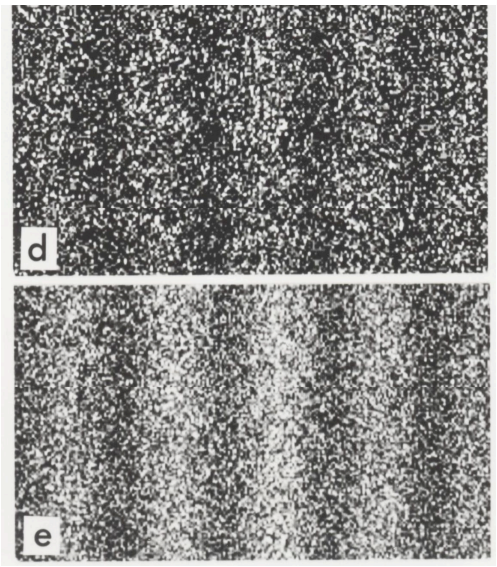
- Two slit experiment, quantum particles:





200 electrons

6,000 electrons

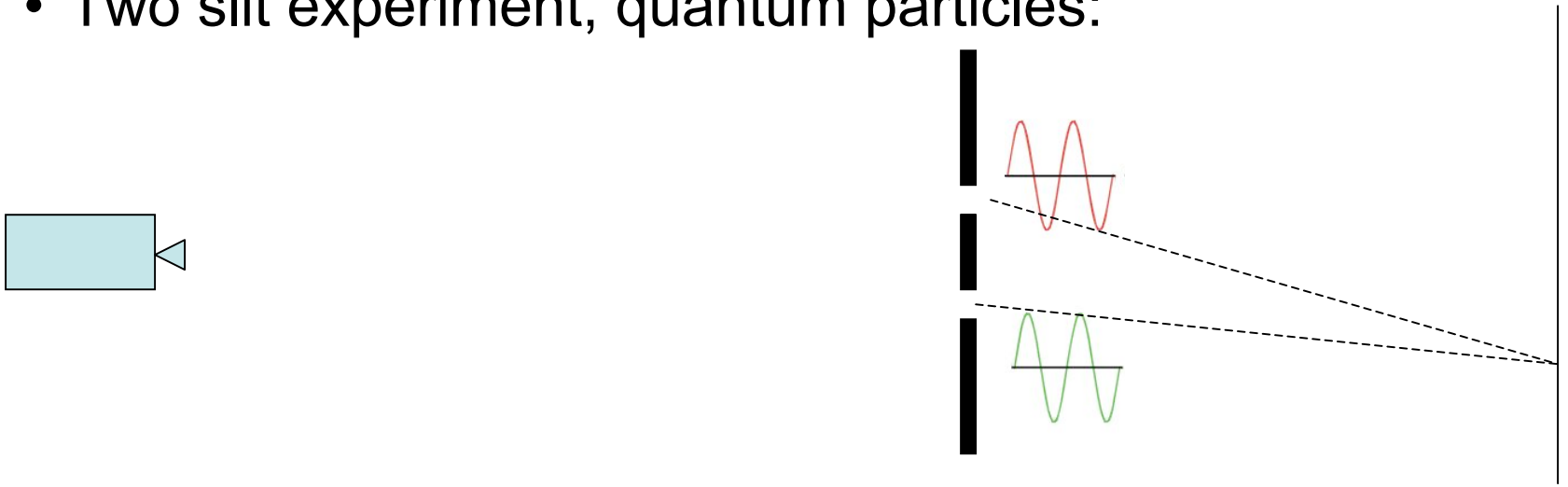


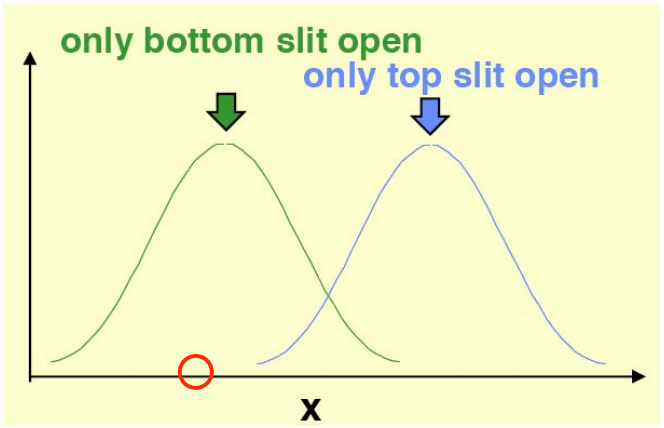
40,000 electrons

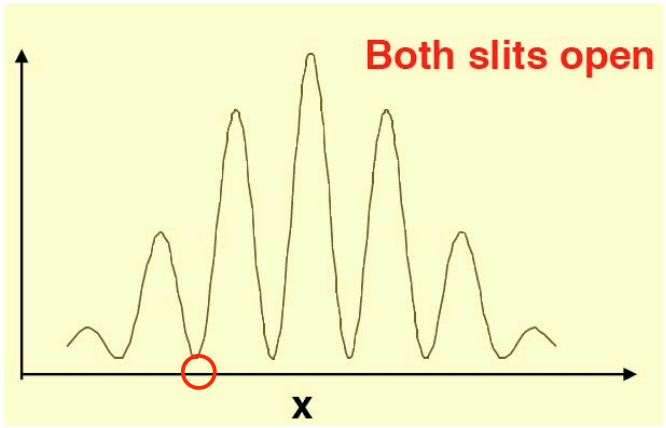
140,000 electrons

Two paths at once?

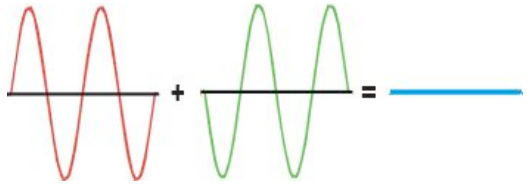
- Two slit experiment, quantum particles:







Each particle “goes through both slits”; think of it as a wave….



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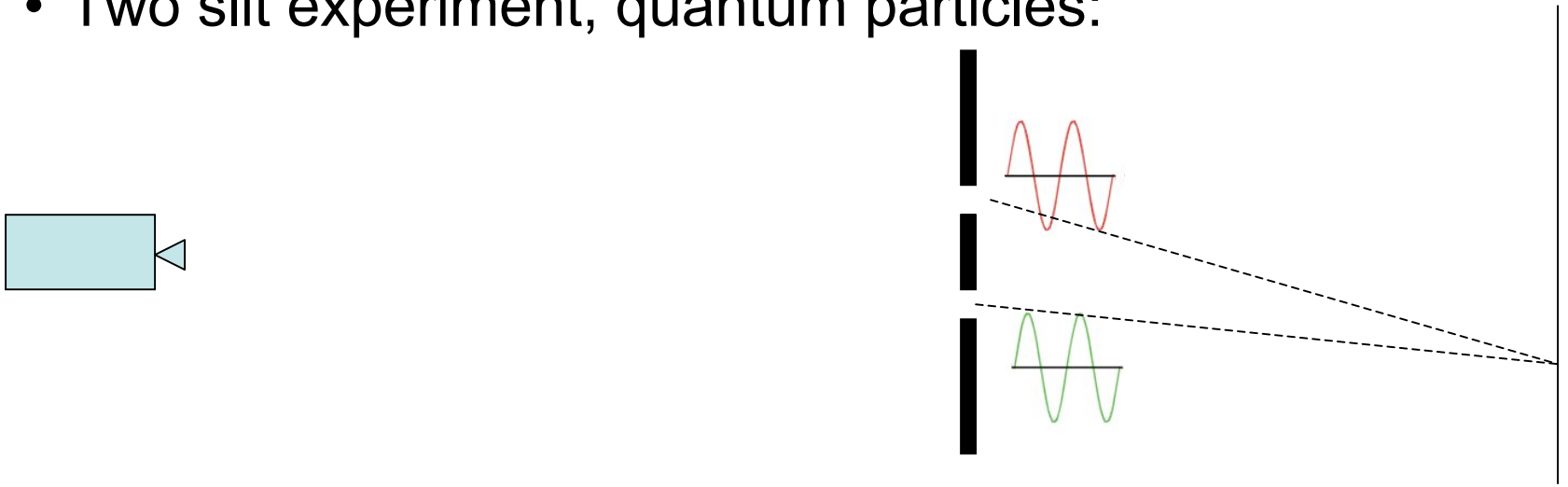

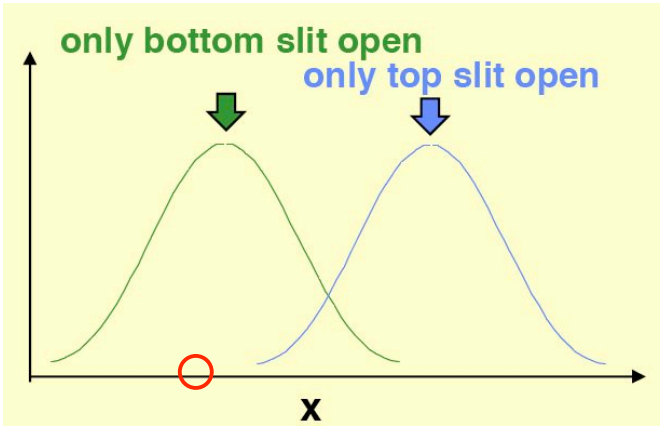

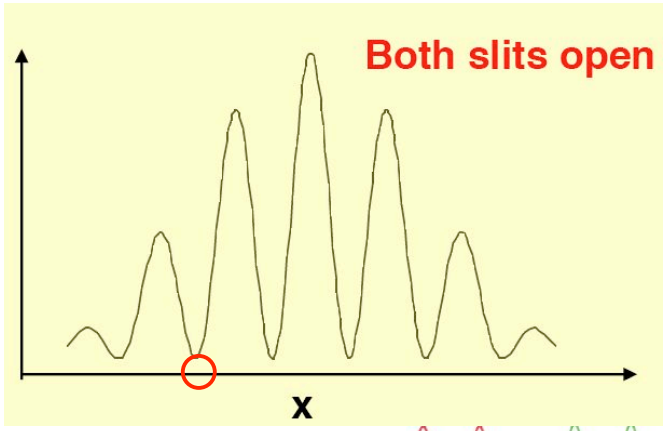

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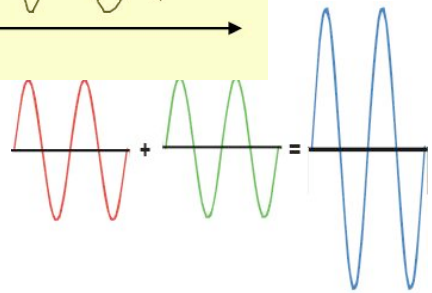
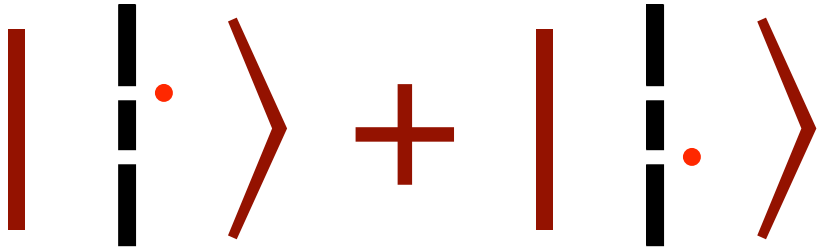
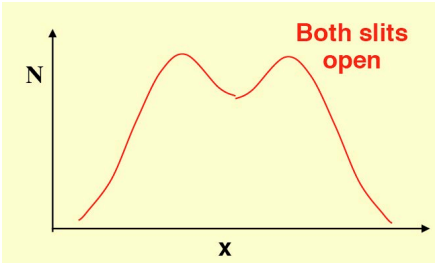


What about in between?

- Before the particle hits the screen, we can't say where it is
- If we were forced, we would say it is in a "state of limbo"…
  ~ in two places at once…

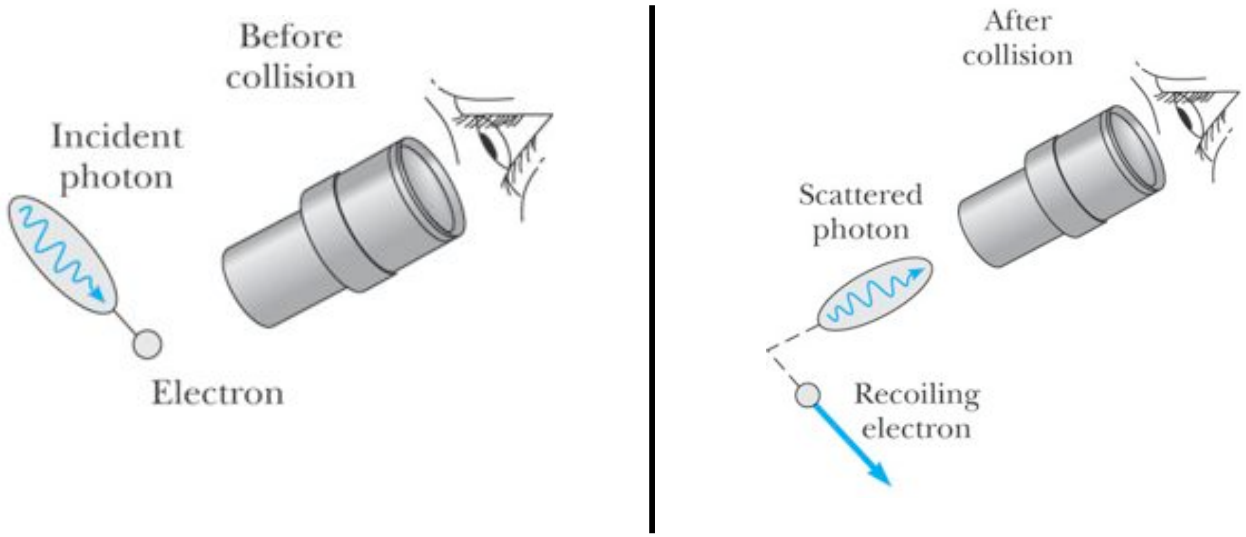


- What if you try to look at the particle right at the slits?
  - Kill the state of limbo!
    - 50% of the time its at the top slit, 50% at the bottom slit
  - Get the boring "classical" pattern

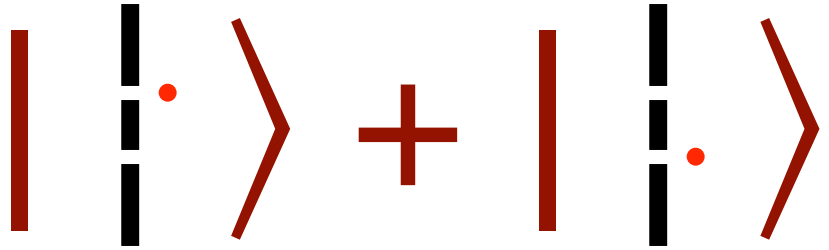


Back-action

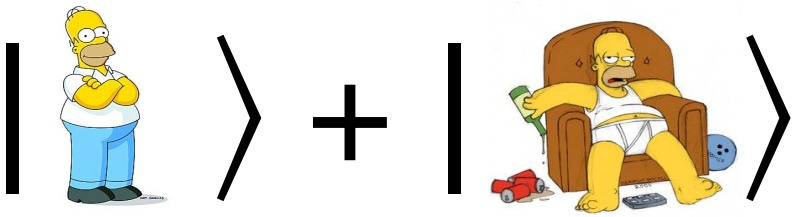
- Why does looking mess up the pattern?
  - Quantum back-action: if you try to measure the position of the particle, you must mess up its speed and direction



Quantum Effects for "Big" Things?



- Can we get objects much bigger than an atom in these "states of limbo"?



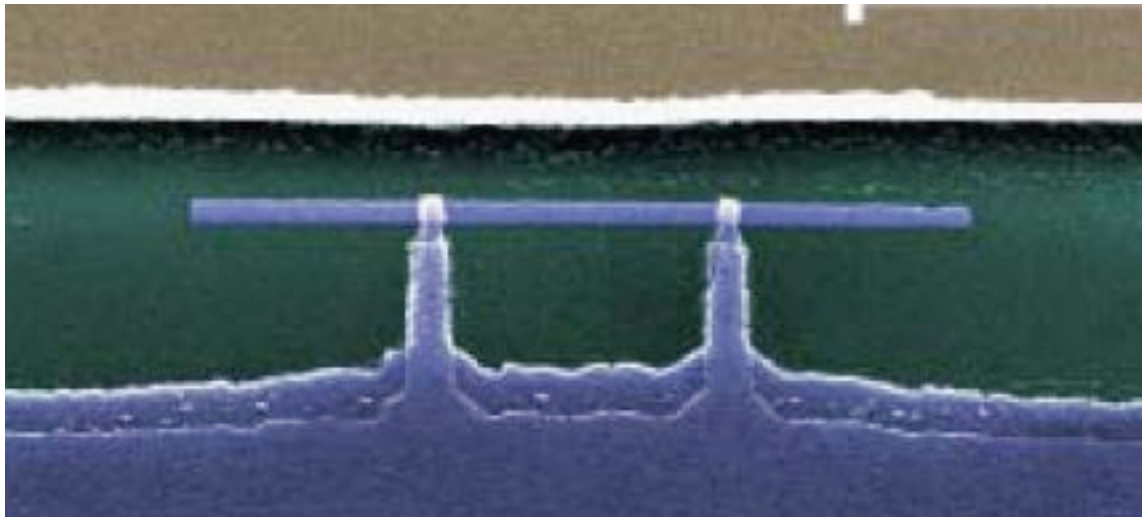
  - Problem: something is always "looking", destroys the interesting state…
- Something I work on:
  - "*Weirdness preservation*": how do you keep a state like this alive? (technical & more respectable term: preventing "decoherence")

Example: Small Chunk of Aluminum

- Acts as an electron box, where the box can have 0 or 2 extra electrons…

10^8 electron pairs	+	10^8+1 electron pairs

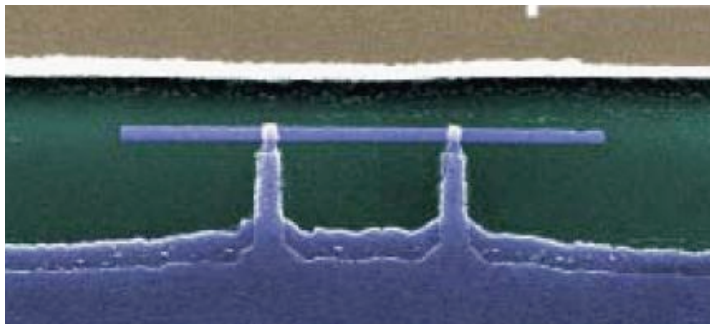
(box is about 5000 nm long = 1/200 of a milimetre)



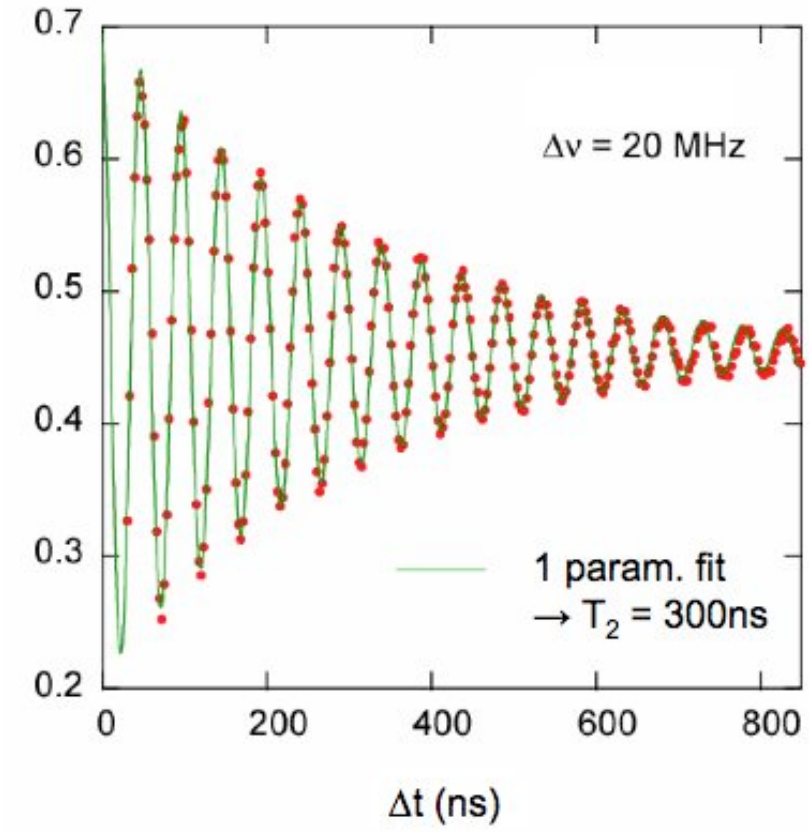
Example: Small Chunk of Aluminum

- Can see that you have a “state of limbo” by doing an interference experiment in time

10^8 electron pairs + 10^8+1 electron pairs

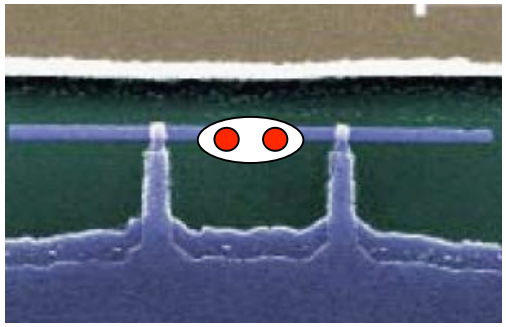


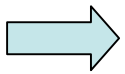
1. Start in 0 state
2. Whack with microwaves
3. Wait a time Δ t
4. Whack with microwaves
5. See if you are back in the 0 state



Why do people pay $$$ for this?

- This could (with a lot of work!) for the basis of a new kind of computer, a ***quantum computer***
  - Classical computer: uses bits to store information
    a bit can be either 0 or 1….
  - Quantum computer: uses quantum bits
    these can be *both* 0 and 1 at the same time!





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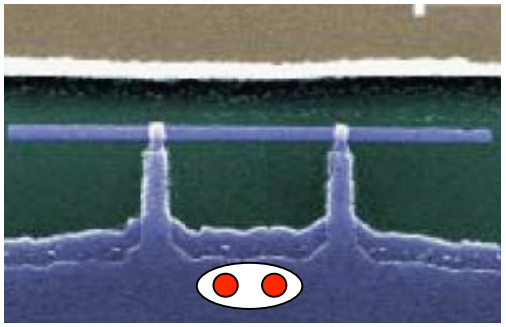

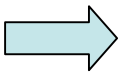

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- In principle, can do things impossible for a normal computer…

Factoring Large Numbers

- It is hard to factor large numbers into product of prime numbers
  - Easy: $15 = 5 \times 3$
  - Hard: $519920419074760465703 = ?? \times ??$
- This is the basis of modern cryptography (i.e. how we have secure transactions on the internet)
- How would a classical computer try to get the factors?

Guess. “Try every key”

Factoring Large Numbers

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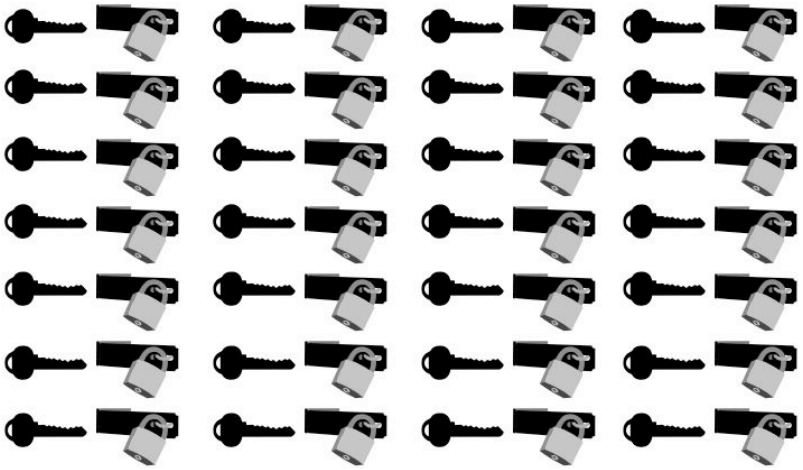

Try all they keys at once! (quantum bits can represent different numbers at the same time!)

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- This is the basis of modern cryptography (i.e. how we have secure transactions on the internet)
- Compare for a 500-digit number:
  - Classical computer: would take 10^{12} years (1 2.5 GHz CPU)
  - Quantum computer: ~ minutes to hours
- A quantum computer could break known codes…

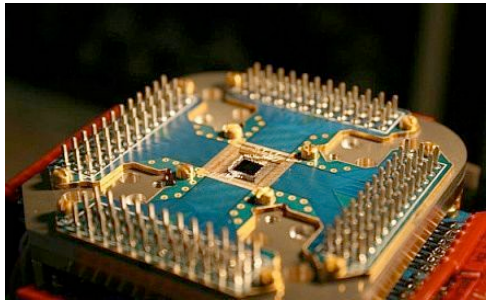
A long way to go…

- A quantum computer has successfully shown that 15 = 5*3 (used 7 qubits)

Experimental realization of Shor's quantum factoring algorithm using nuclear magnetic resonance

Lieven M. K. Vandersypen*†, Matthias Steffen*†, Gregory Breyta*, Costantino S. Yannoni*, Mark H. Sherwood* & Isaac L. Chuang*†

- A company in BC claims to have solved a Sudoku(!) using 16 qubits; their result is very controversial…

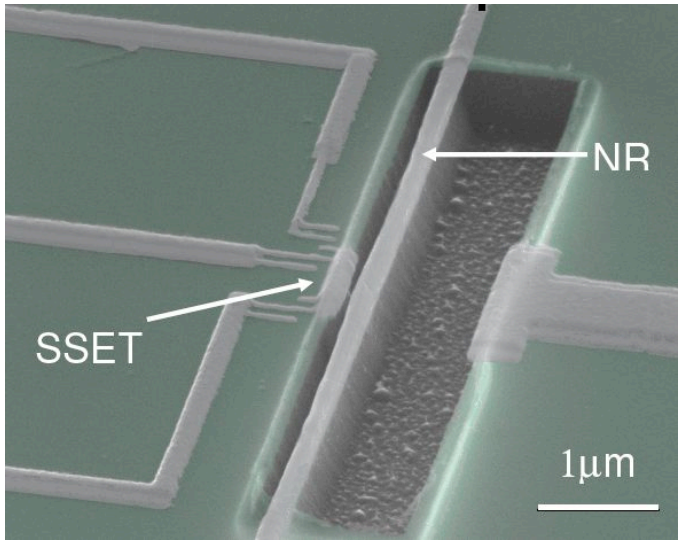


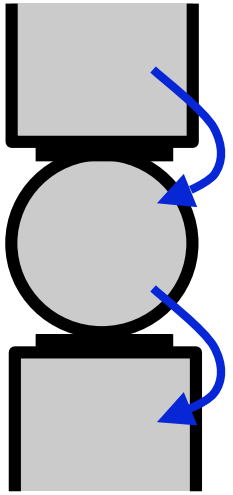
D-Wave
The Quantum Computing Company™

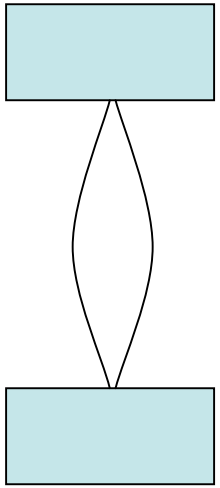
Since 1999, they have received $38 million in funding, half from the Canadian government…

Another system: small vibrating beam

- Can we see quantum behaviour in the beam?



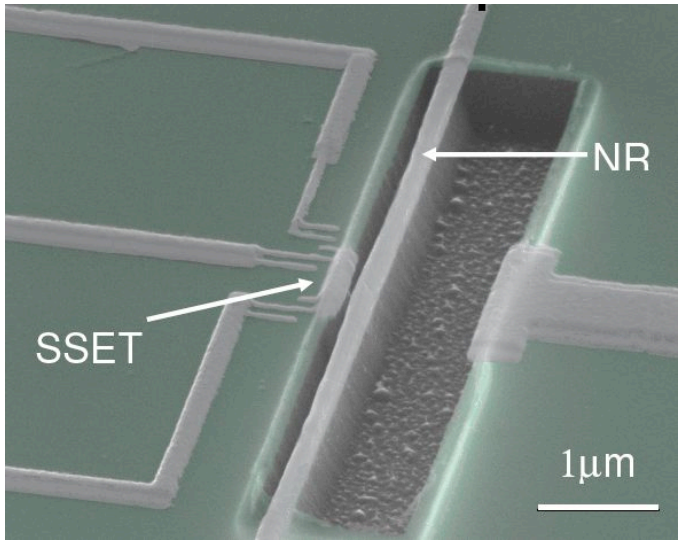


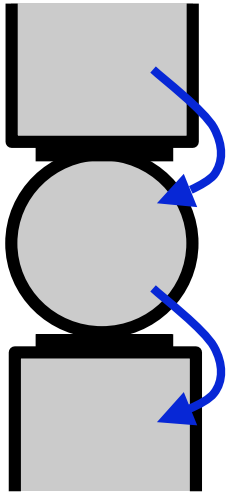


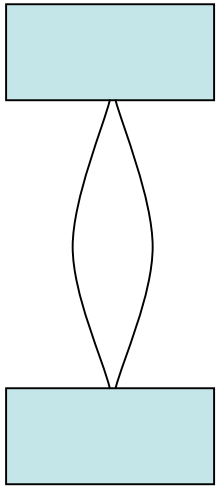
- Measuring current tells you about position of beam… can do this as well as quantum mechanics allows!
  - Can detection motion with amplitude less than 0.001 nm!

Another system: small vibrating beam

- Can we see quantum behaviour in the beam?



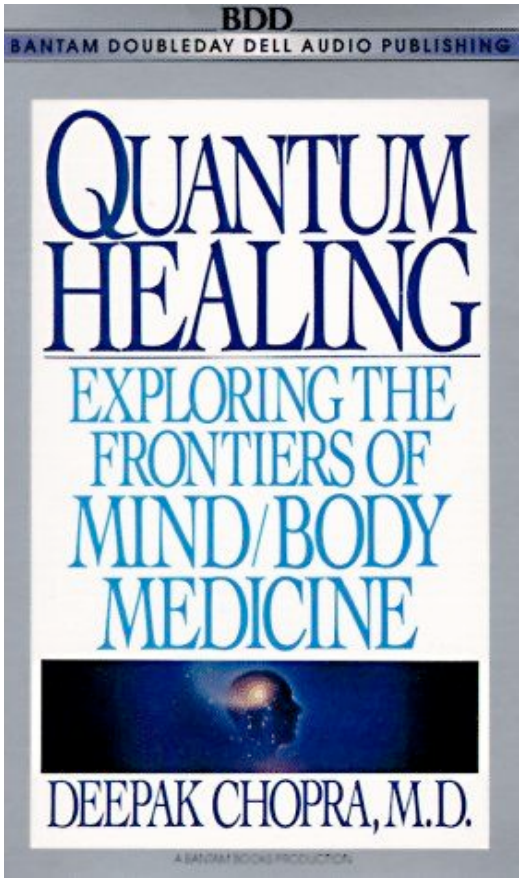




- Have seen the quantum "back-action": pairs of electrons kick the beam
  - Even stranger: these kicks can cool the beam
  - "*Quantum mother-in-law effect*"
    = making something cold by looking at it.

END

Quantum Weirdness vs. Weird uses of the word “Quantum”



“Our bodies ultimately are fields of information, intelligence and energy. Quantum healing involves a shift in the fields of energy information, so as to bring about a correction in an idea that has gone wrong.”

(Winner of the Ig Nobel prize in physics, 1998)