Title: Quantum Physics

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Abstract: Quantum theory is the most accurate scientific theory humanity has ever devised. But it is also the most mysterious. No one knows what the underlying picture of reality at quantum level is. This presentation will introduce you to some of the many interpretations of quantum theory that scientists have devised and discuss the infamous 'measurement problem'.

Interpreting Quantum Theory

Lucien Hardy

Perimeter Institute

The Elitzur Vaidman Bomb Puzzle

Have a factory [factory drawing] that makes [bomb drawing labeled Bomb, with "handle" and "trigger"] bombs!

The trigger is so sensitive that if a single particle of any sort what so ever hits it the bomb will EXPLODE!!!

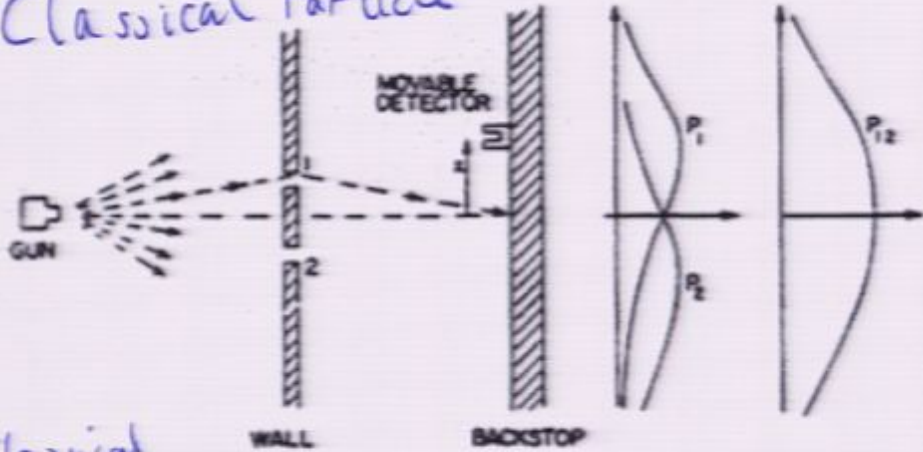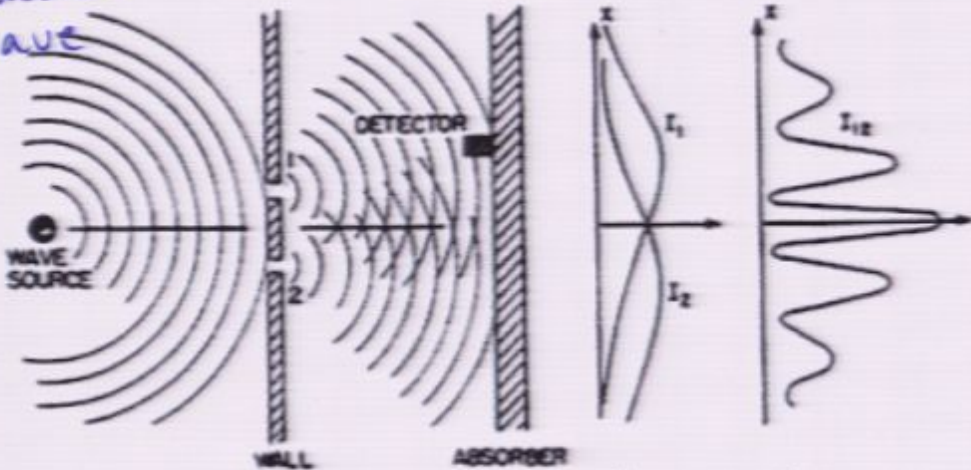The manufacturing process is imperfect and sometimes the trigger is missing

Good bomb [bomb drawing labeled Bomb with trigger]   [bomb drawing labeled Bomb without trigger] bad bomb

The puzzle: Is it ever possible to know we have a good bomb without exploding it? (It is ok if we explode some bombs in the process.)
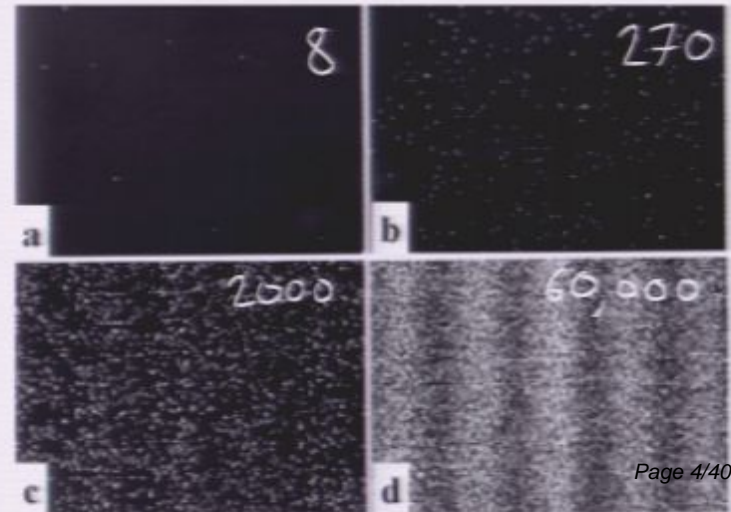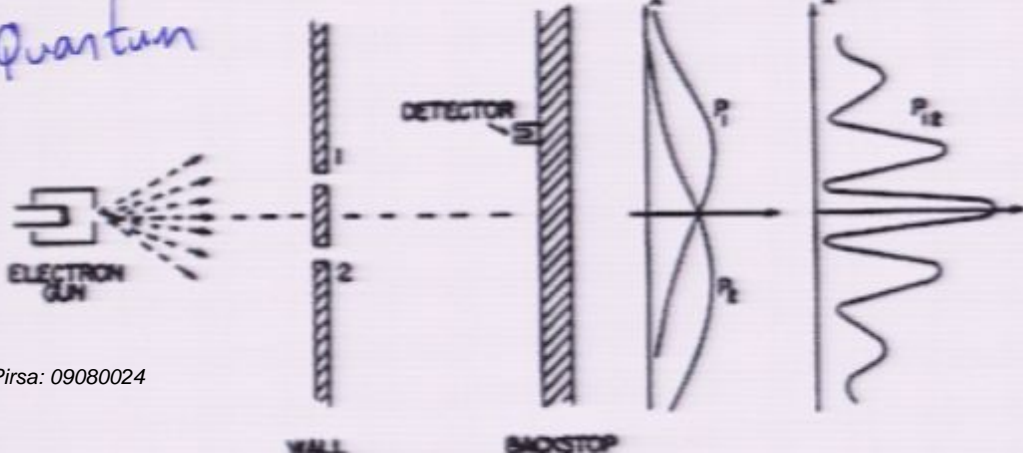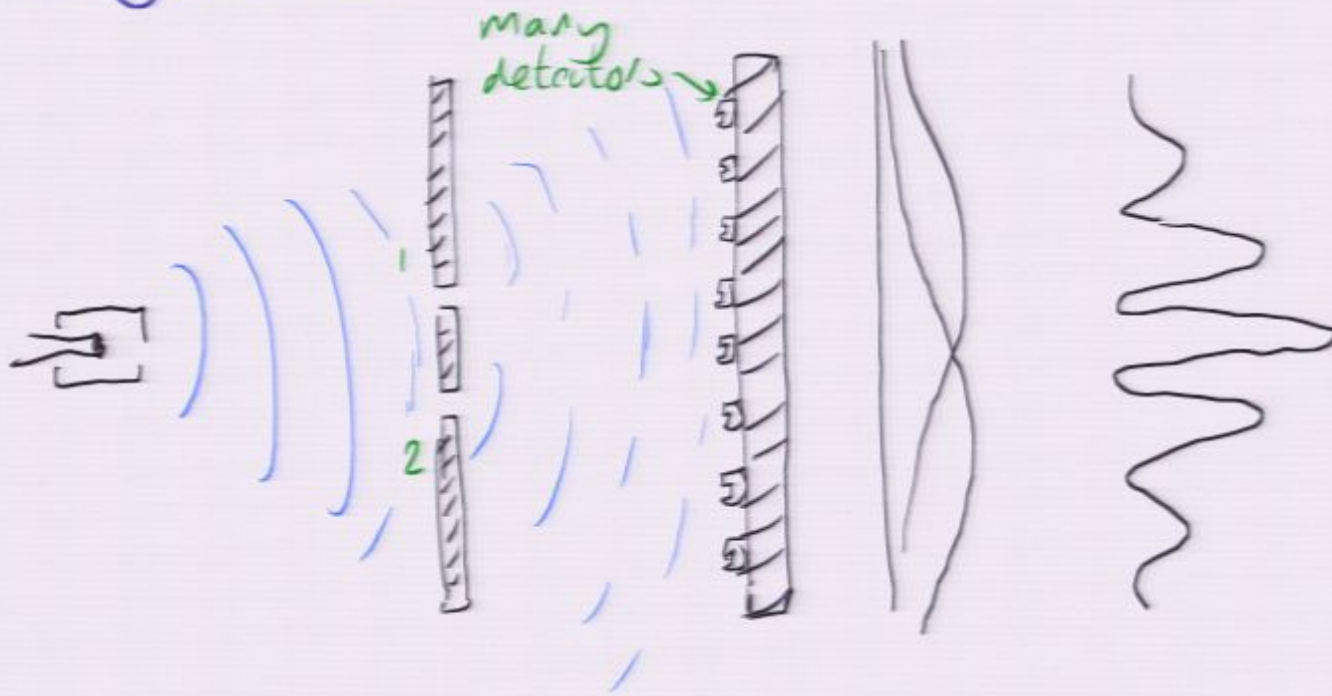
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Classical Particle

GUN

MOVABLE DETECTOR

WALL   BACKSTOP

P_1

P_2

P_{12}

Interference

Classical wave

WAVE SOURCE

DETECTOR

WALL   ABSORBER

I_1

I_2

I_{12}

Quantum

ELECTRON GUN

DETECTOR

P_1

P_2

P_{12}

8	270
a	b
2000	60,000
c	d

Single-electron Build-up of Interference Pattern

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Why simple wave picture fails

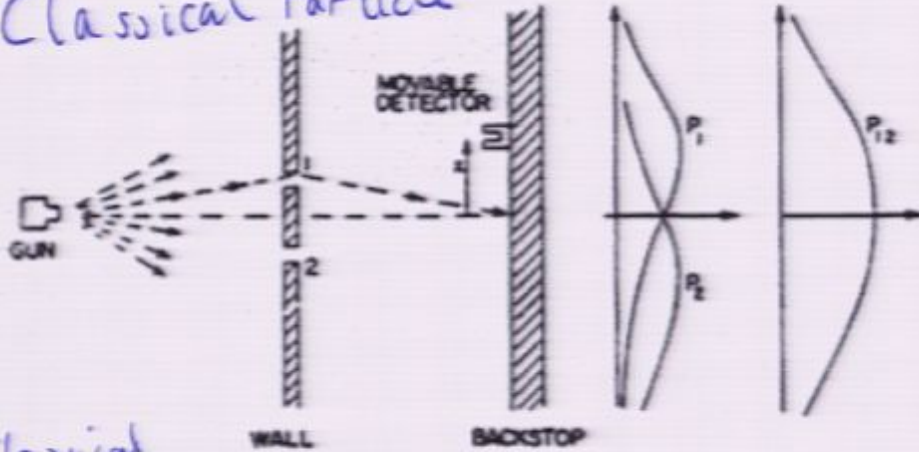*Many detectors*
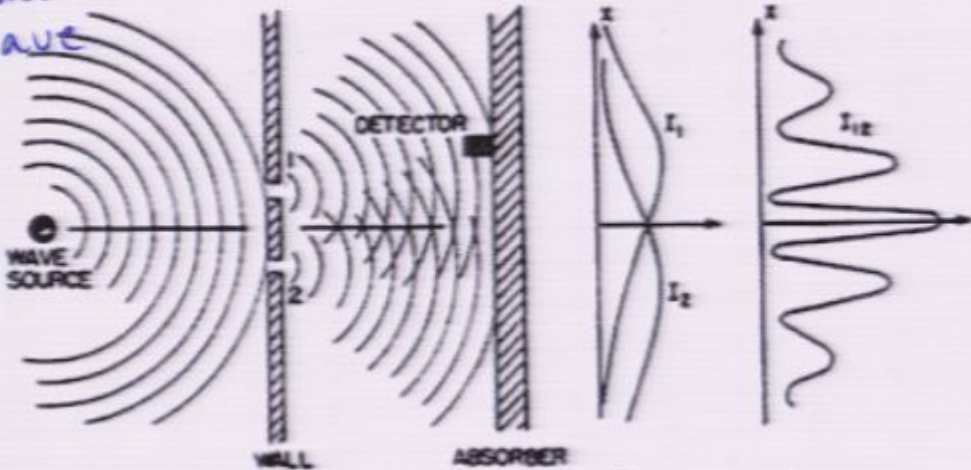
A water wave could be seen at all detectors

How does quantum wave "know" only to be seen at one detector?

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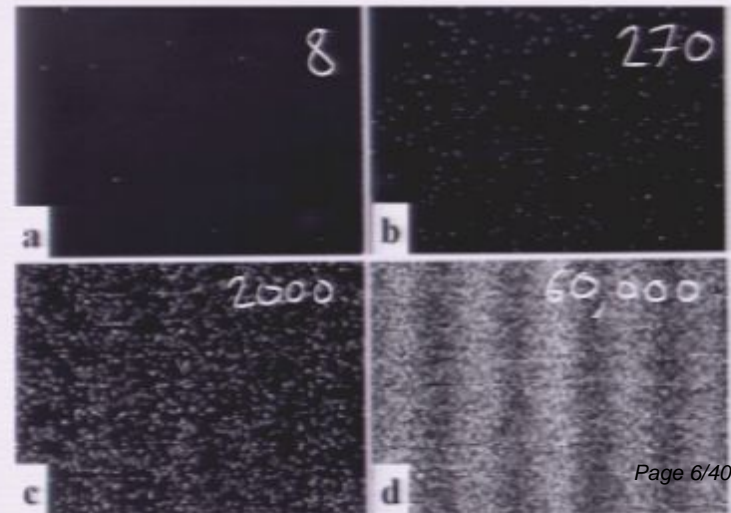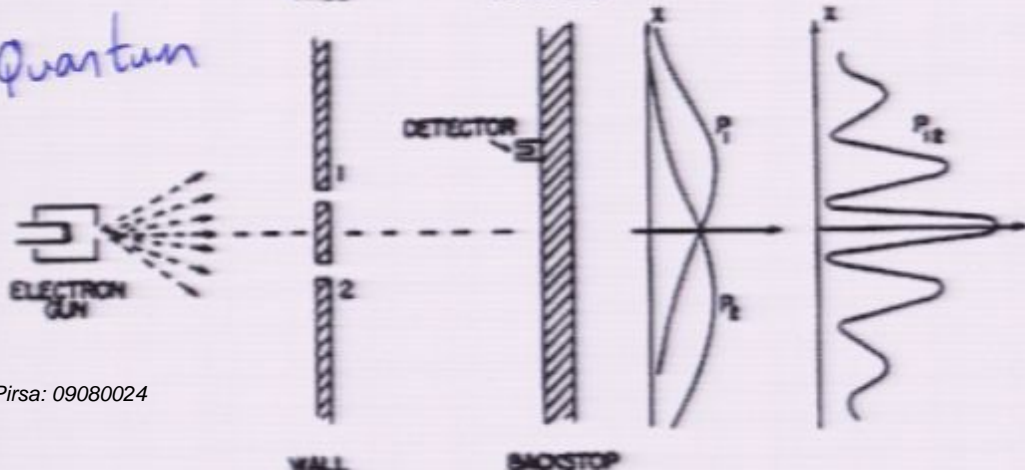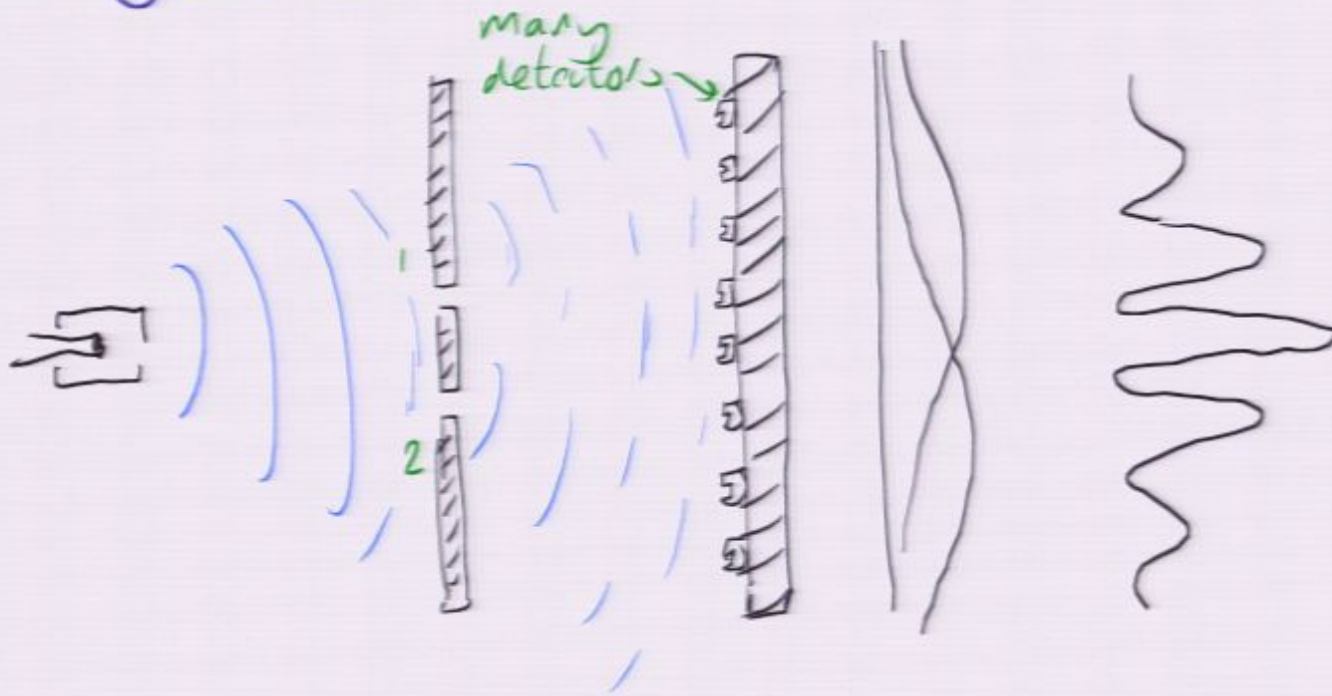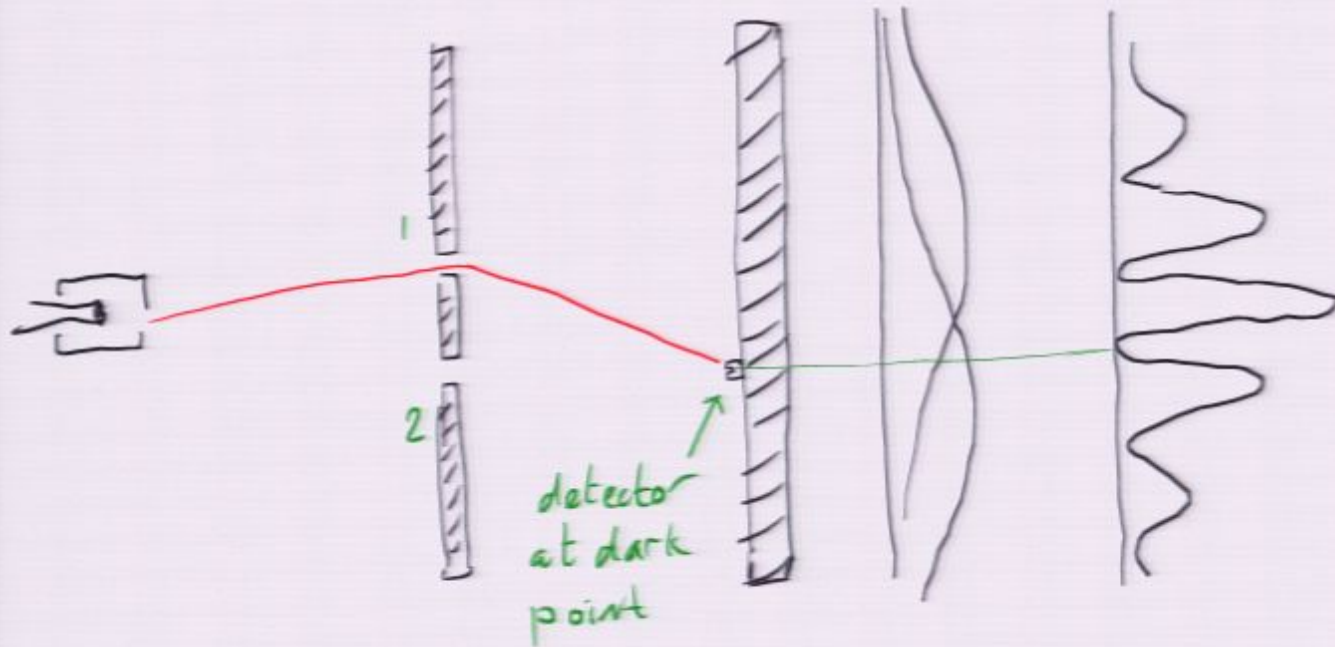How does quantum wave "know" only to be seen at one detector?

Why particle only picture Fails

1

2

detector
at dark
point

If slit 2 closed can take **red** path

If slit 2 open cannot take **red** path

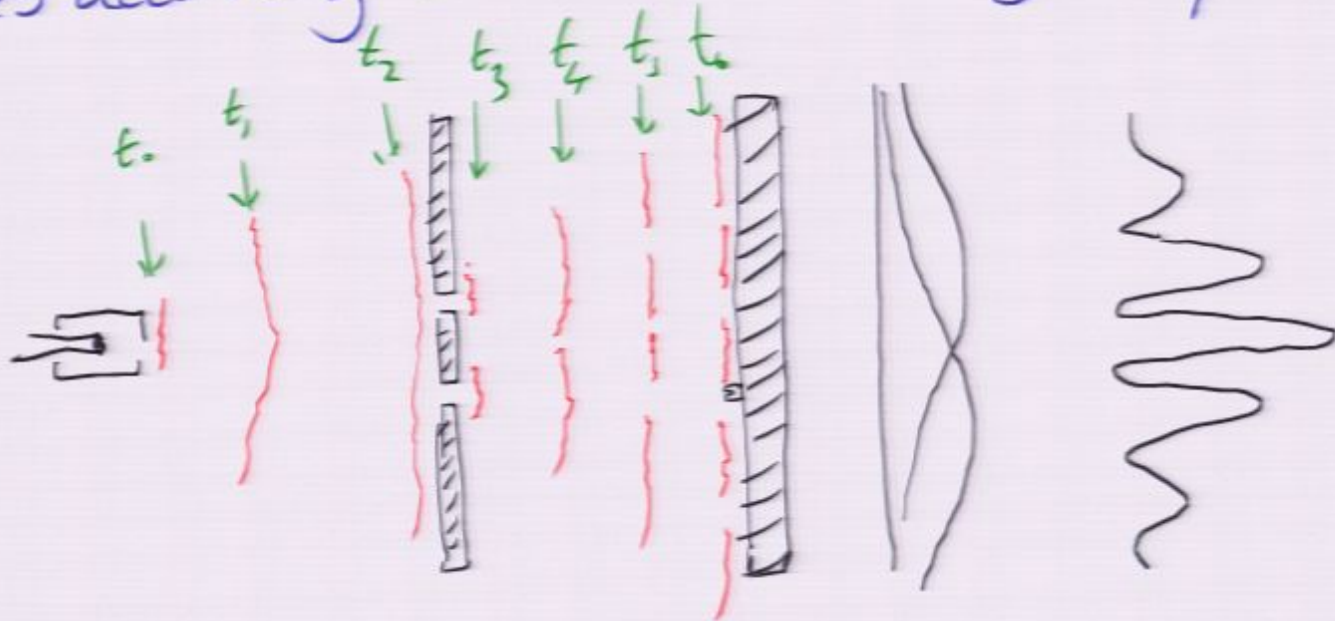But how does particle "know" about slit 2 if it takes red path?

Something must go through both slits each time.

The Quantum State

The Quantum State is given by the wavefunction
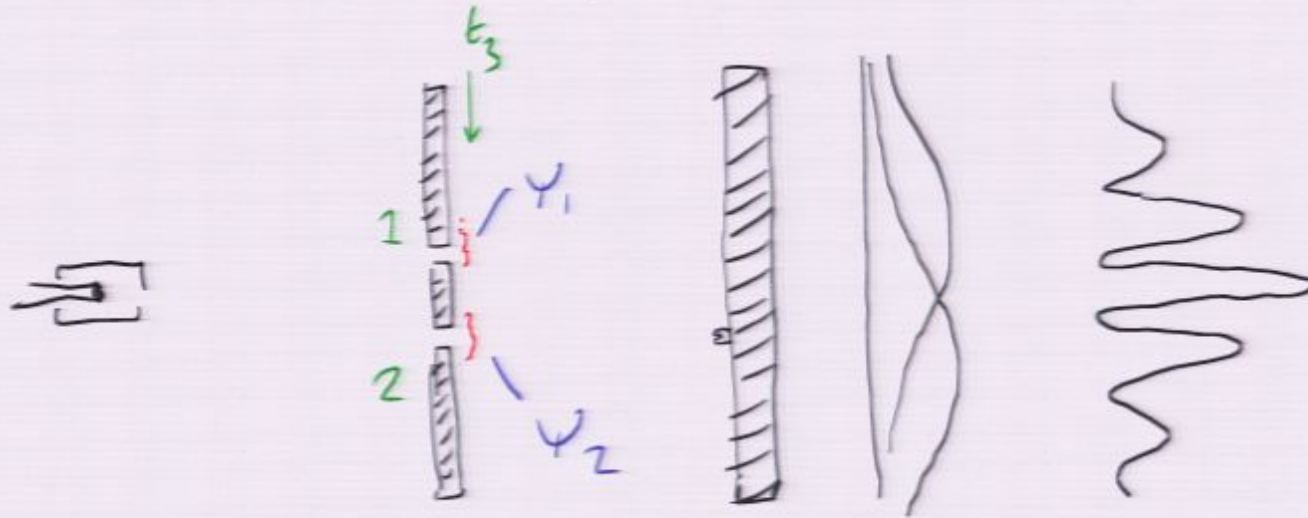
$$\psi(x,t)$$

Evolves according to the Schrödinger equation

Have

$$\text{probability} = |\psi(x,t)|^2$$

Quantum Superposition

t_3

1

2

ψ_1

ψ_2

At time t_3 have superposition of two possibilities:

not just a probability distribution

$$\psi = \psi_1 + \psi_2$$

Both terms are necessary and seem to be real

state = "particle passes through slit 1" + "particle passes through slit 2"

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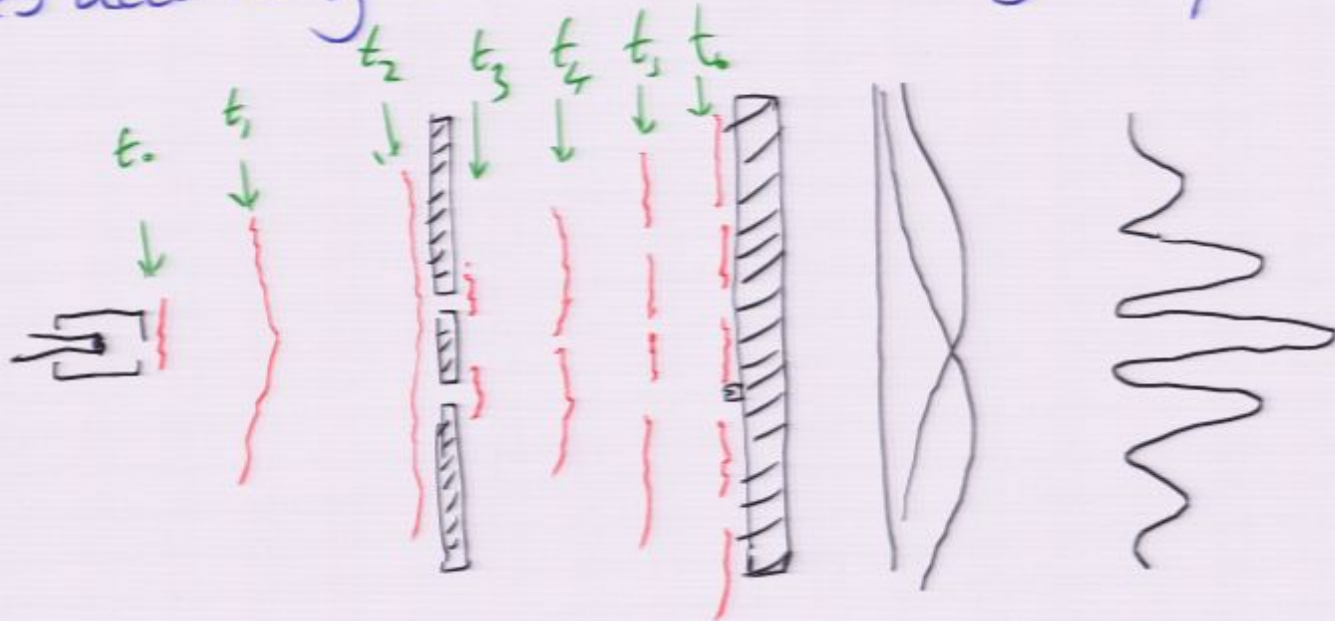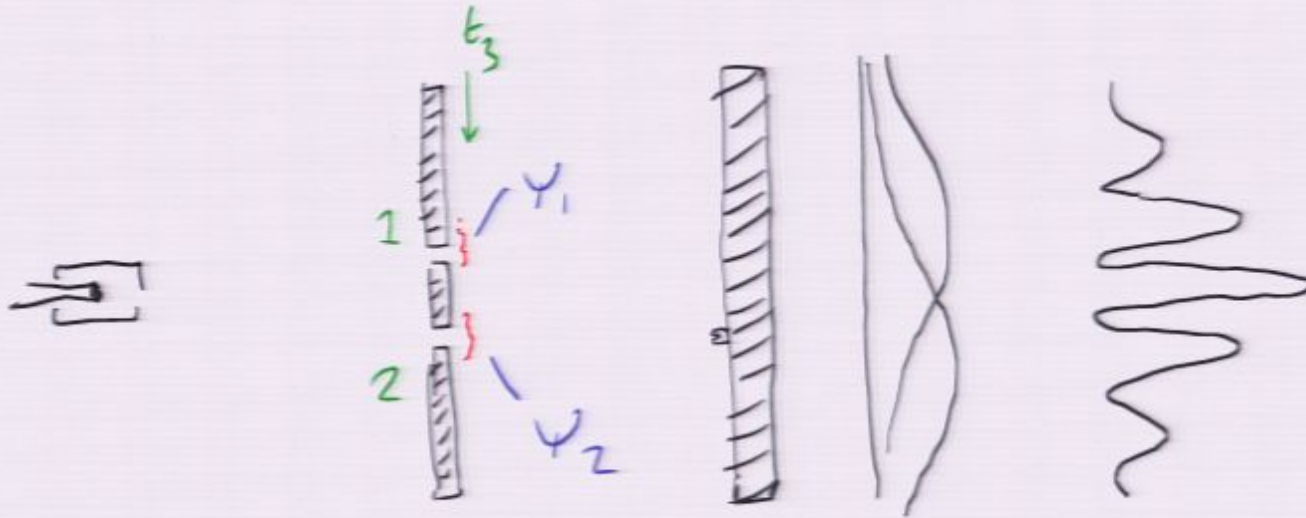
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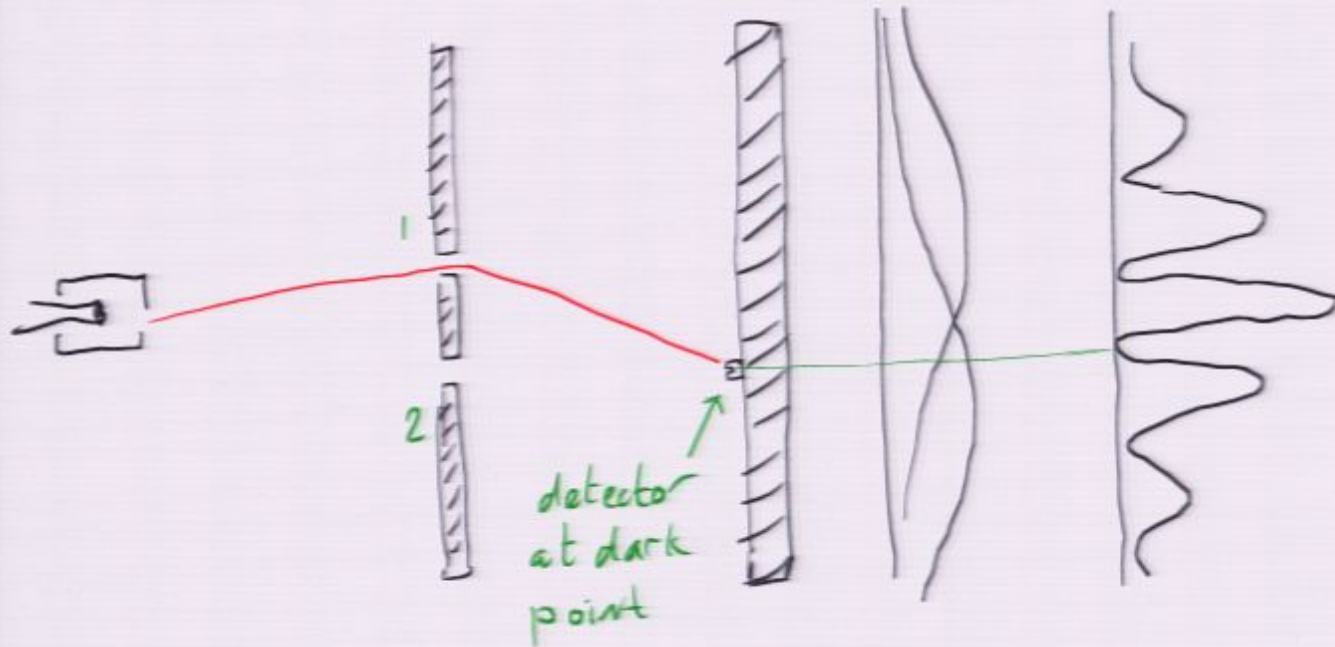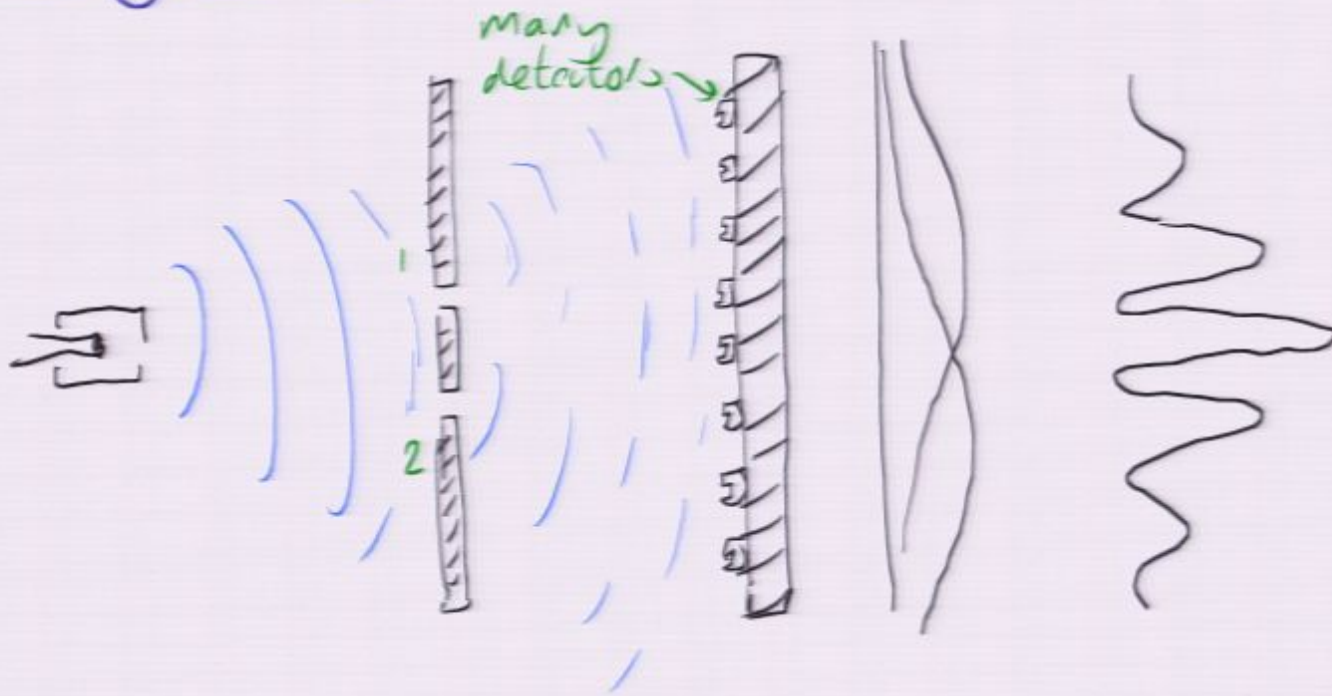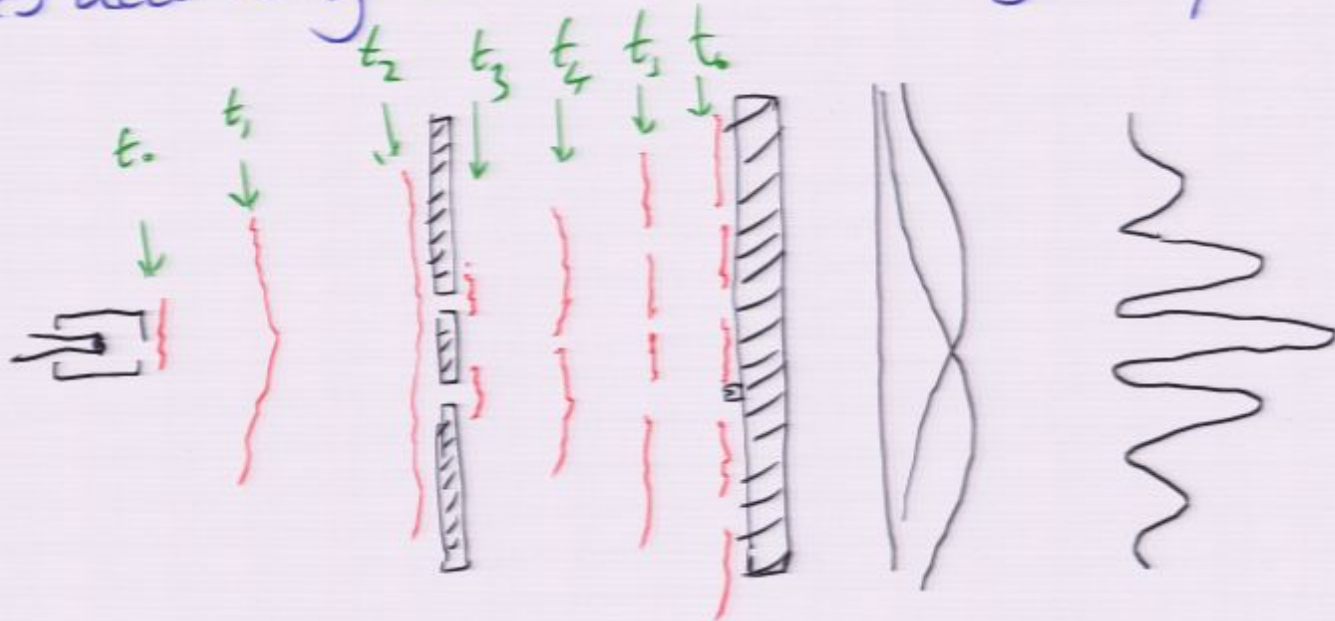
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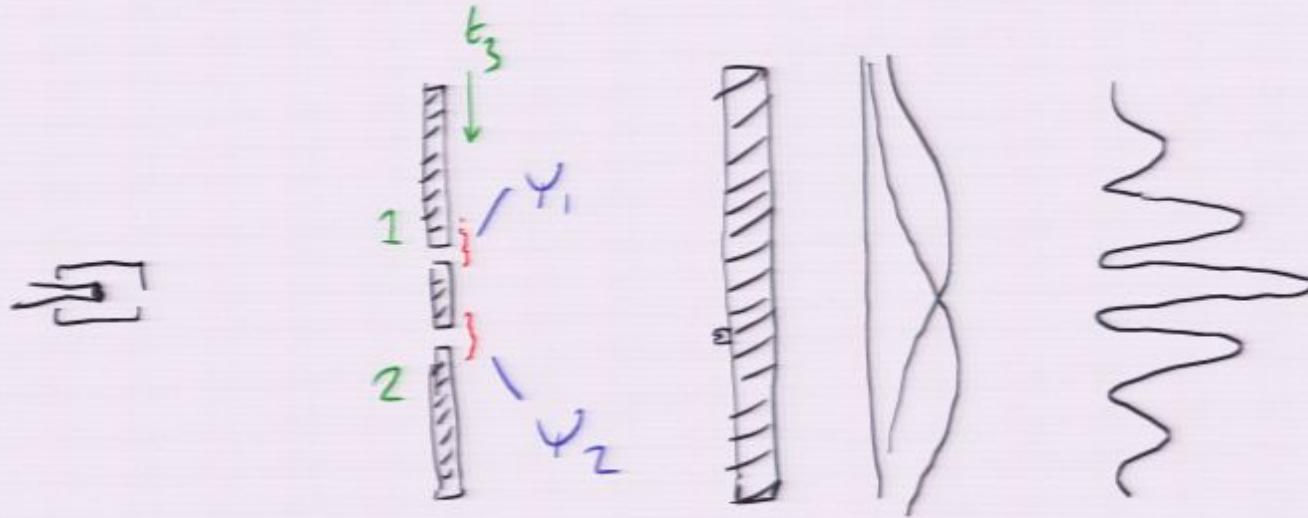
not just a probability distribution

Both terms are necessary and seem to be real

$$state = \text{"particle passes through slit } \underline{1}\text{"} + \text{"particle passes through slit 2"}$$

... But where does it stop

state = "electron at position 1" + "electron at position 2"

electron   atom   molecule   cell   cat   human   galaxy   whole universe
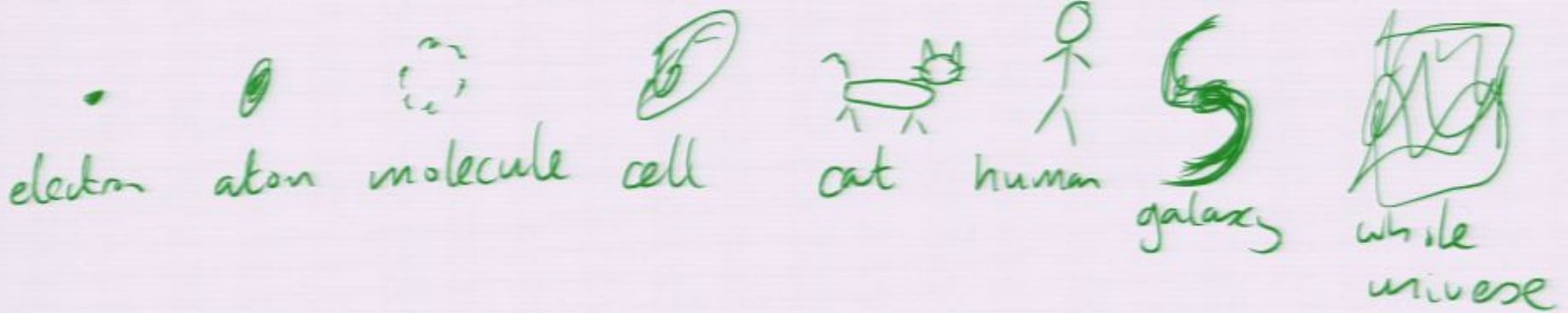
The Schrödinger equation knows no bounds!!

Schrödinger's Cat
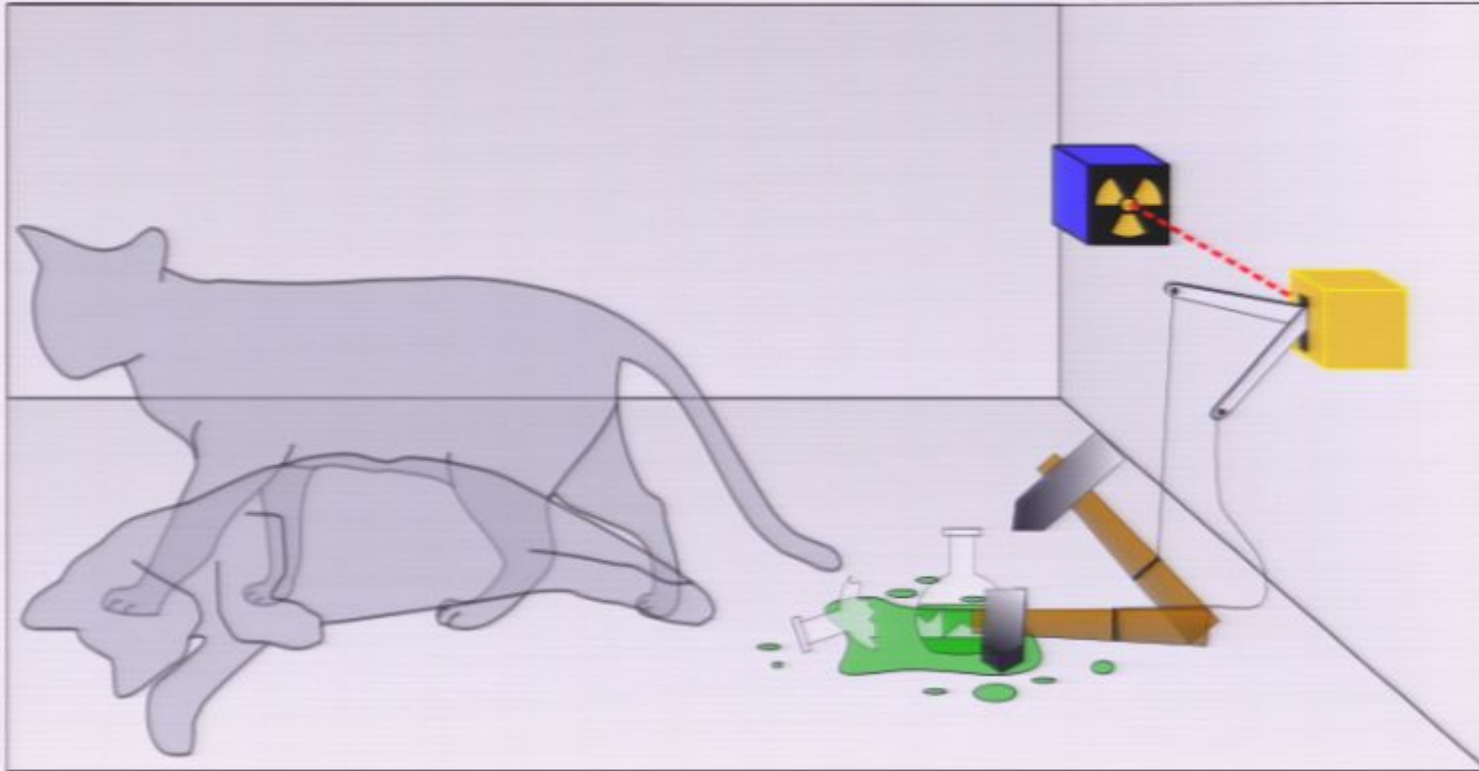
state = "Cat alive" + "cat dead"

The Reality Problem

(The measurement problem)

The quantum state has both cat alive and cat dead but this is not what we see — we just see one.

Reality (as we see it) ⟷ quantum state

The Reality Problem

Reality (as we see it) ⟷ classical state

OK in classical physics

We need an interpretation of QT

Two types of interpretation:

Realist { make an honest attempt to describe the underlying reality

Instrumentalist { keep description of reality at level of instruments

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Why Realism?

Some people believe a physical theory should describe the way the world _is_.

Why Instrumentalism?

By thinking about how we actually measure something may avoid unwarrented metaphysical assumptions.

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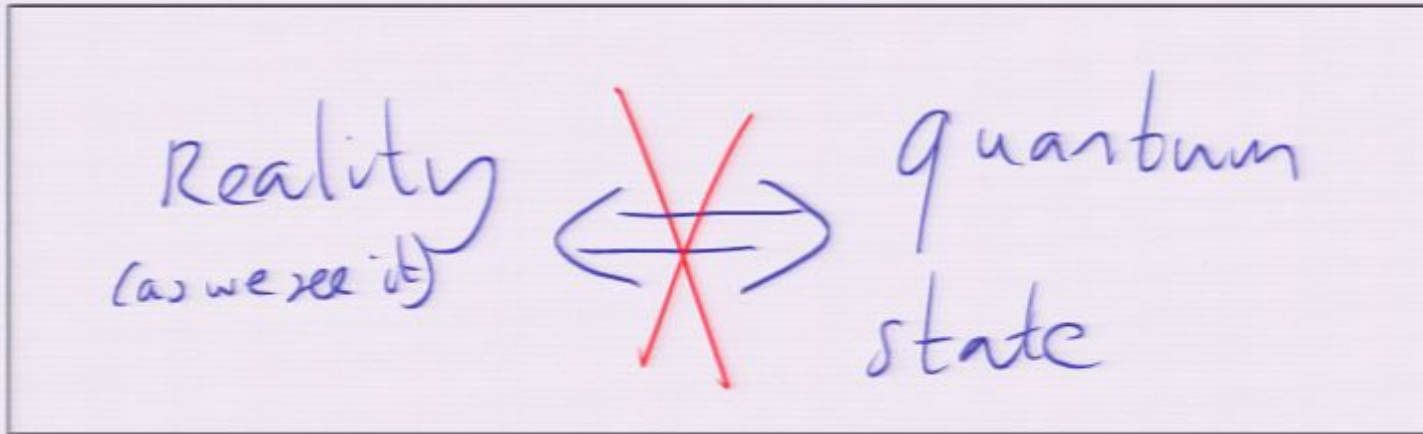Some people believe a physical theory should describe the way the world _is_.

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The Realist interpretation

Two choices:

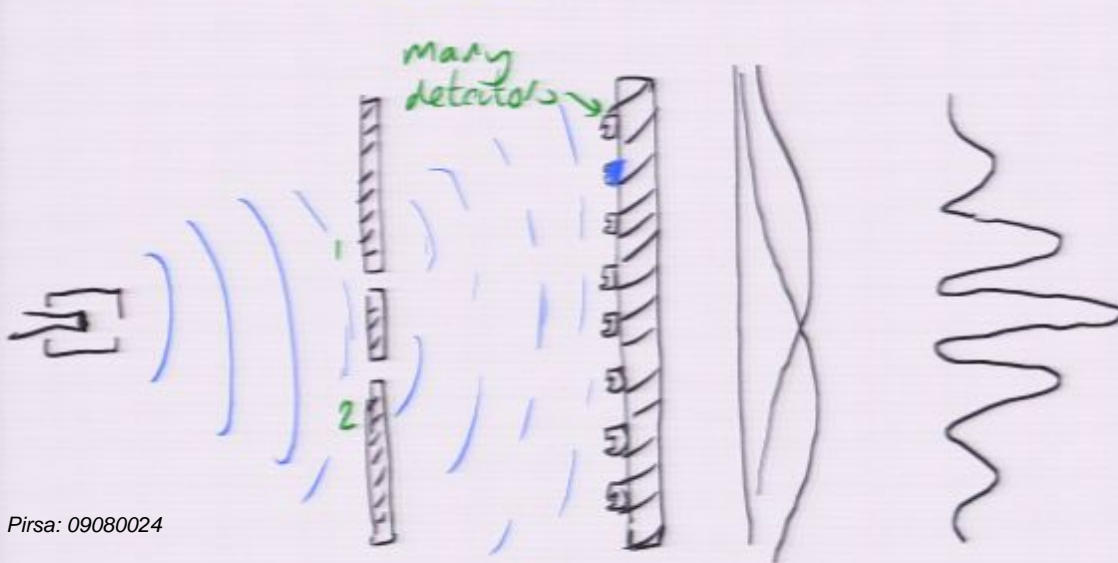1) Introduce collapse by modifying Schrodinger's equation

2) Add something to state description

Ψ	collapse	no collapse
add something	$\times$	pilot wave model
don't add something	collapse models	many worlds

Collapse Models

Can change Schrödinger equation so that

1) small things like electrons hardly effected
   (still see interference with them)

2) big things will collapse very quickly
   (so cat is either alive or dead).

many detectors →

Detectors are big things so wave function collapses when detectors get involved — we only see one detector fire

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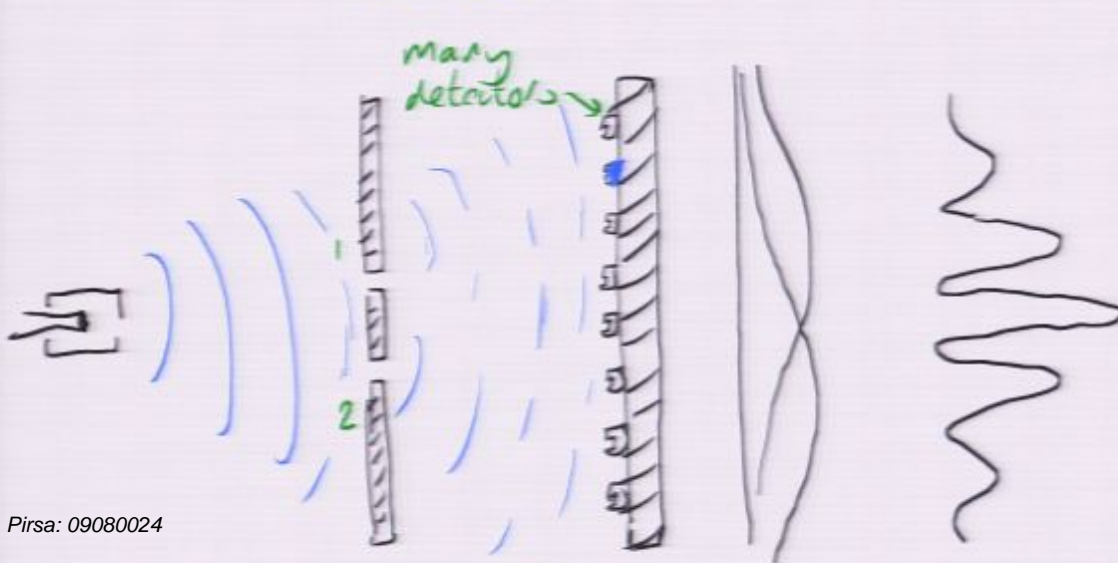
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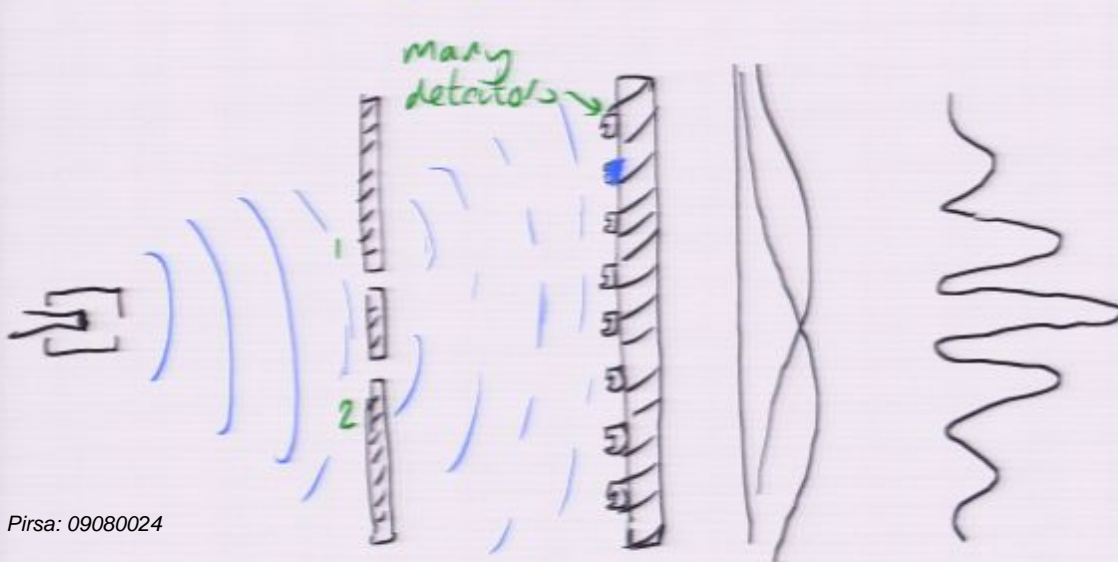
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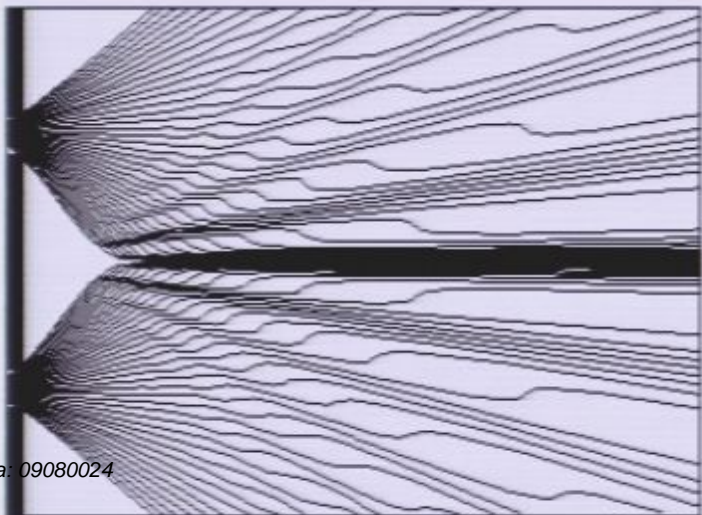
Pilot wave model   de Broglie 1927   Bohm 1952

Have both a wave and a particle.

The wave guides the particle according to a particular equation

$$\frac{dx}{dt} = \frac{\hbar}{m} \operatorname{Im}\left(\psi^* \frac{d\psi}{dt} / \psi^* \psi\right)$$

Solves measurement problem because particle picks out one of the possibilities: cat is either dead or alive.

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The many worlds interpretation
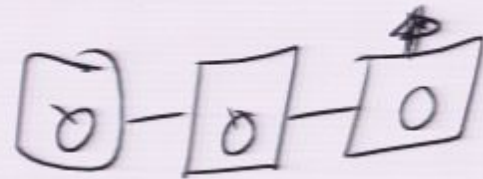
Reality is described by ψ alone.

Can think of world splitting every time you might see more than one possibility.

$$\text{"cat alive"} \atop \begin{array}{c}\text{\& you see}\\\text{cat alive}\end{array} \quad + \quad \text{"cat dead"} \atop \begin{array}{c}\text{\& you see}\\\text{cat dead}\end{array}$$

In many worlds interpretation both actually happen.

Instrumentalism (operationalism)

As methodology

As a philosophy

no reality beyond
instrument

The Copenhagen Interpretation

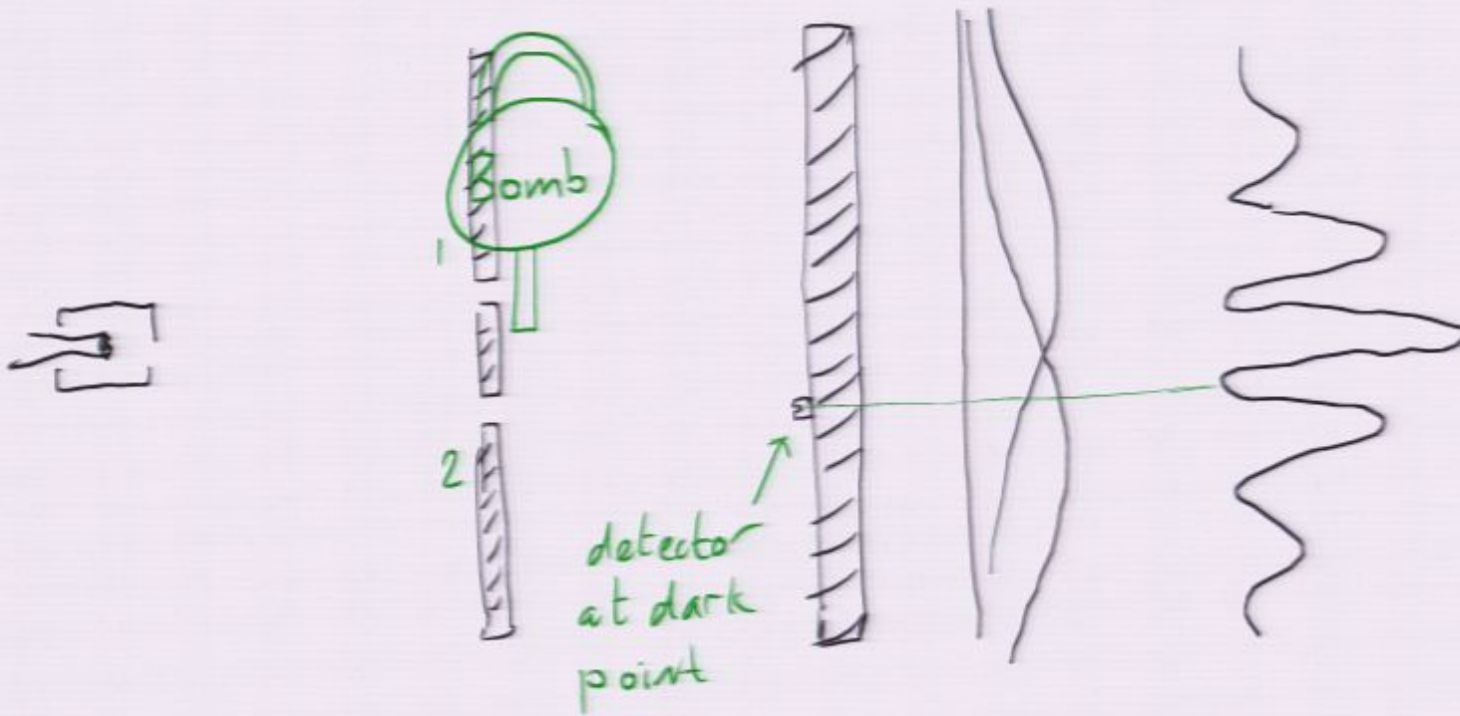.. complementarity .. ..

Other issues in QT

1) Nonlocality

2) Quantum Gravity

The future?

Quantum Gravity will have a big
impact on the interpretation of Quantum Theory

Instrumentation is a powerful
methodology but ultimately we
want to describe reality

Finally ... the bomb

Bomb

1

2

detector
at dark
point

If detector fires must have a good bomb