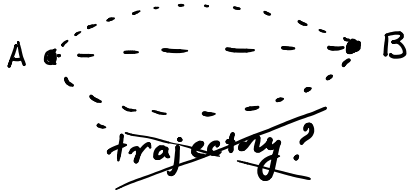
Quantum Mechanics & Quantum Computation

Umesh V. Vazirani
University of California, Berkeley

Lecture 1: Introduction

Double Slit Experiment



Successful

* Conductivity of metals
* Transparency of glass
* Colors
* Chemical reactions
* ⋮

Young's Double Slit Experiment.

Rain of particles/bullets — Wave

Newton
Planck
Einstein
photons
1905

??

Young
Maxwell — em-wave

Electrons

Electron diffraction –

✓

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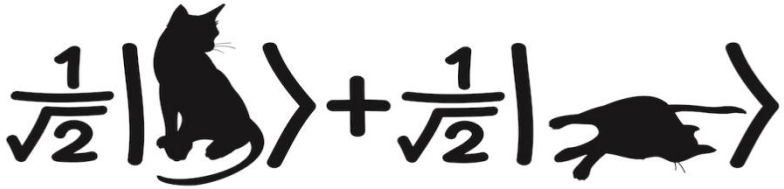

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Double-slit experiment

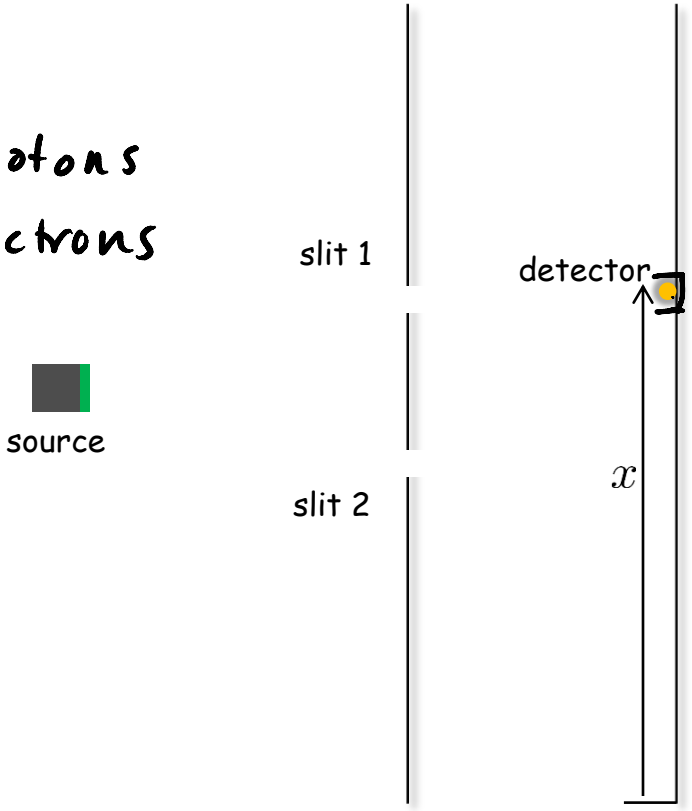
Wave or Particle?

Light: rain of particles
waves

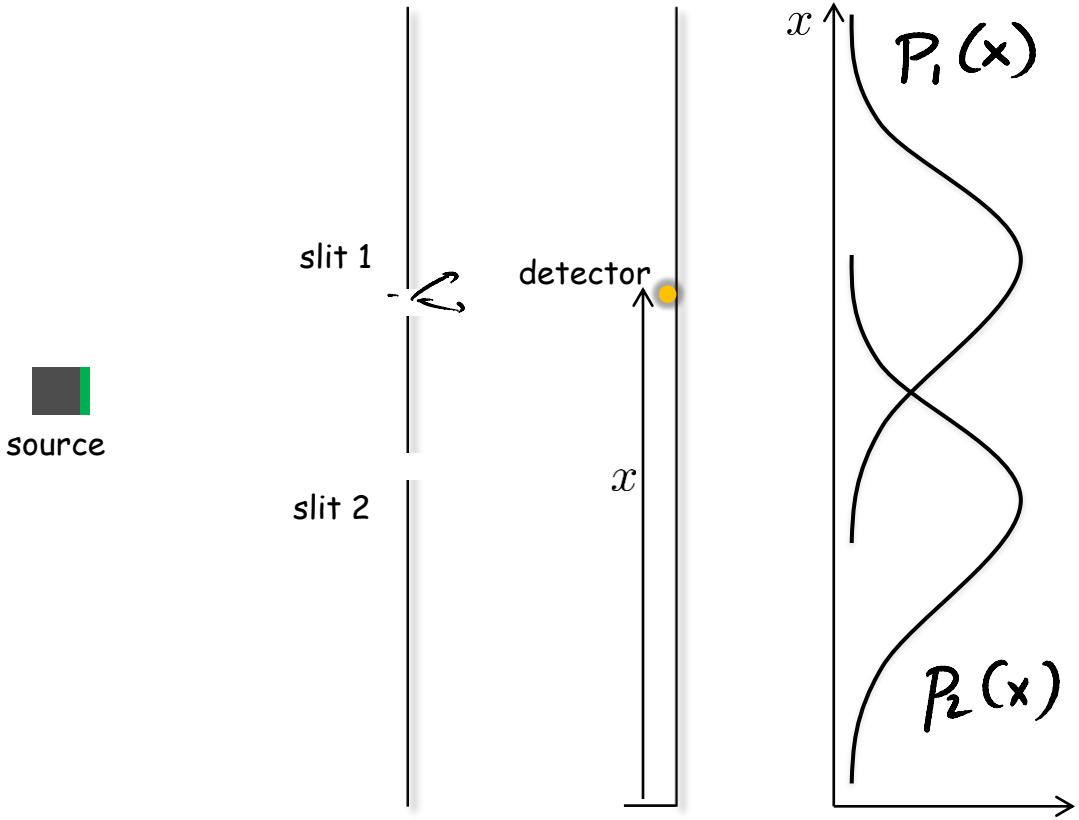
Electrons: particles
wave (electron diffraction)

Double-slit experiment

photons
electrons



Double-slit experiment



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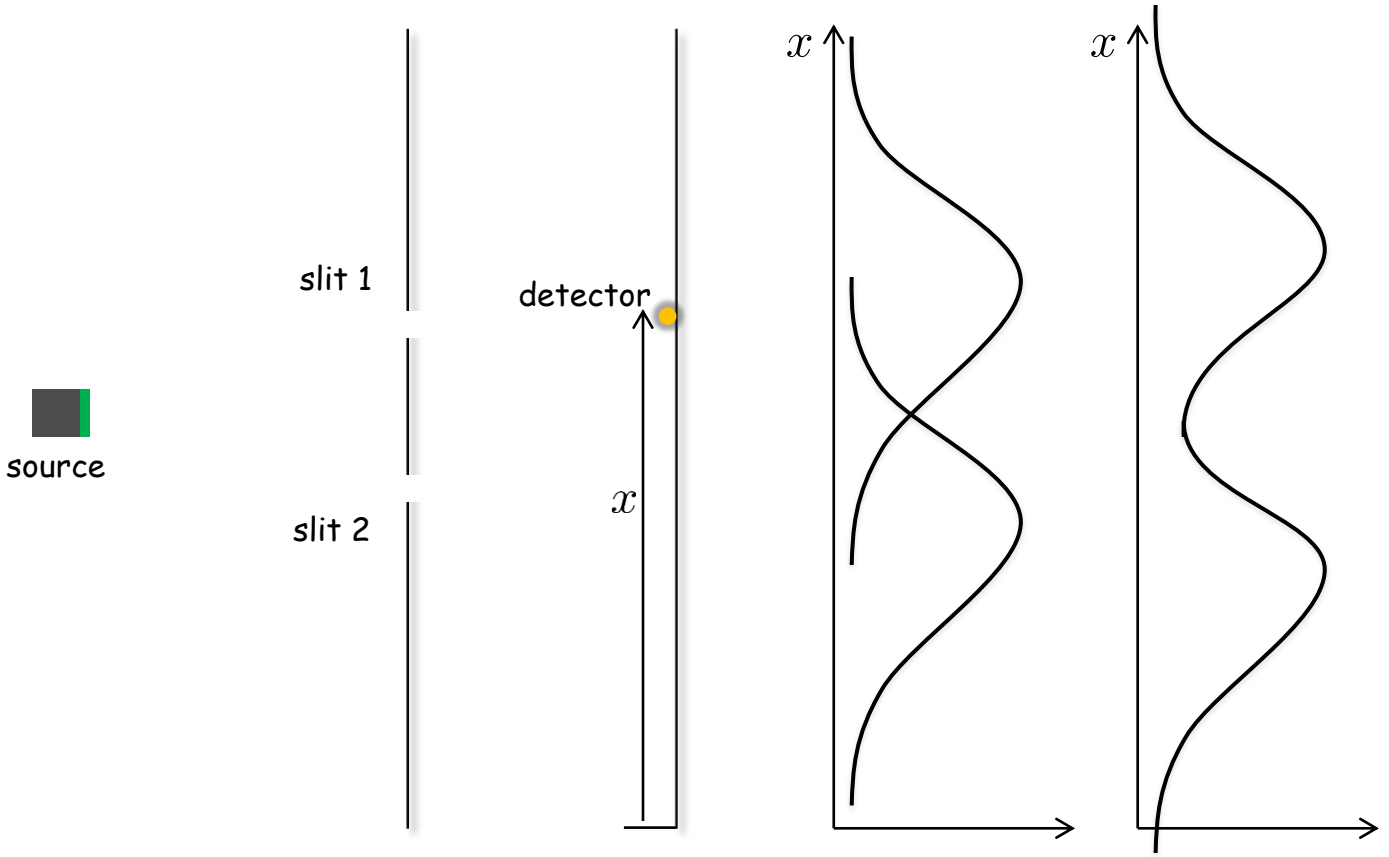

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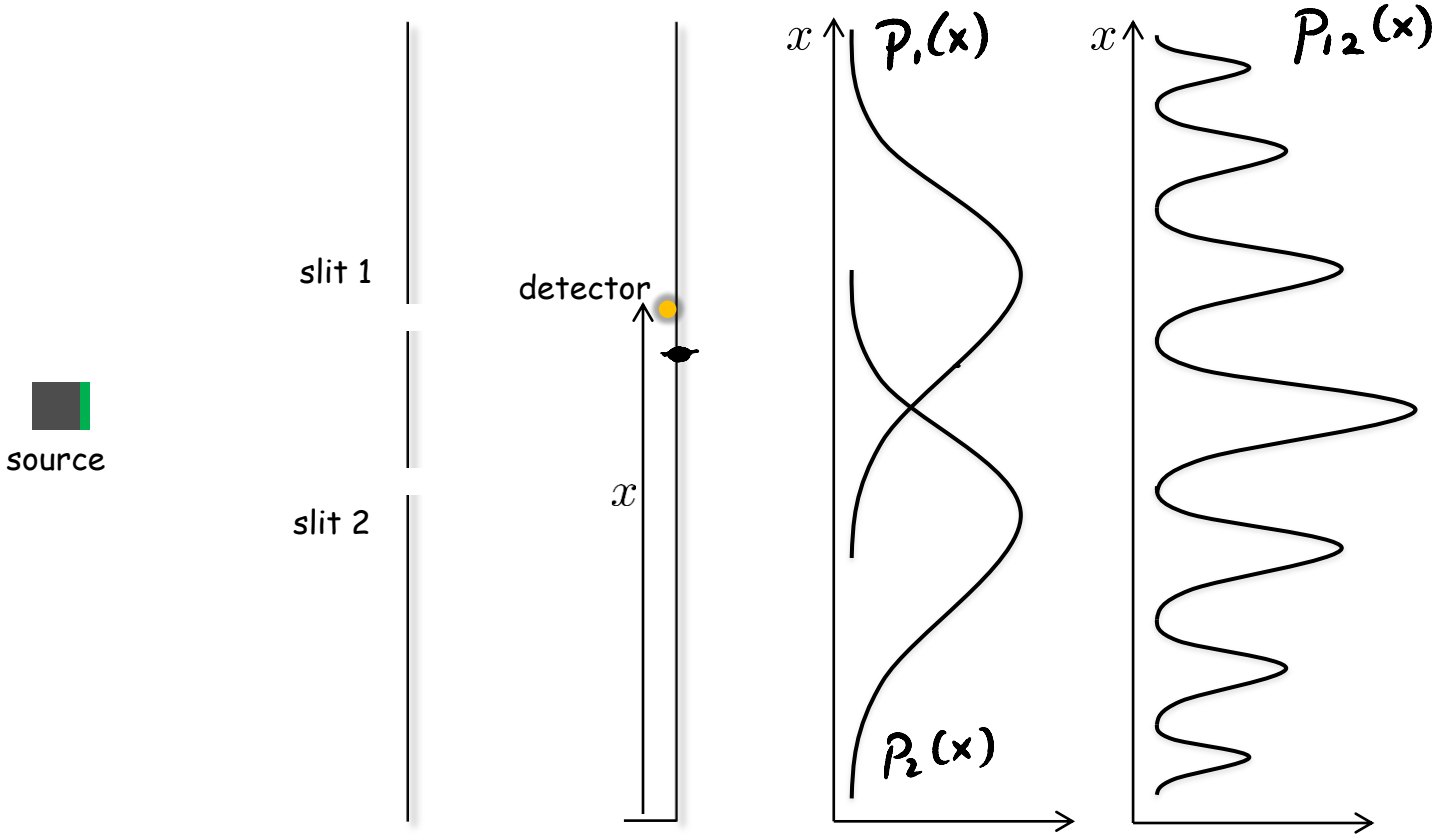

I can safely say that no one understands quantum mechanics.

- Richard Feynman

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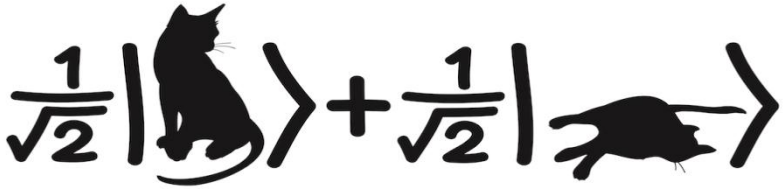

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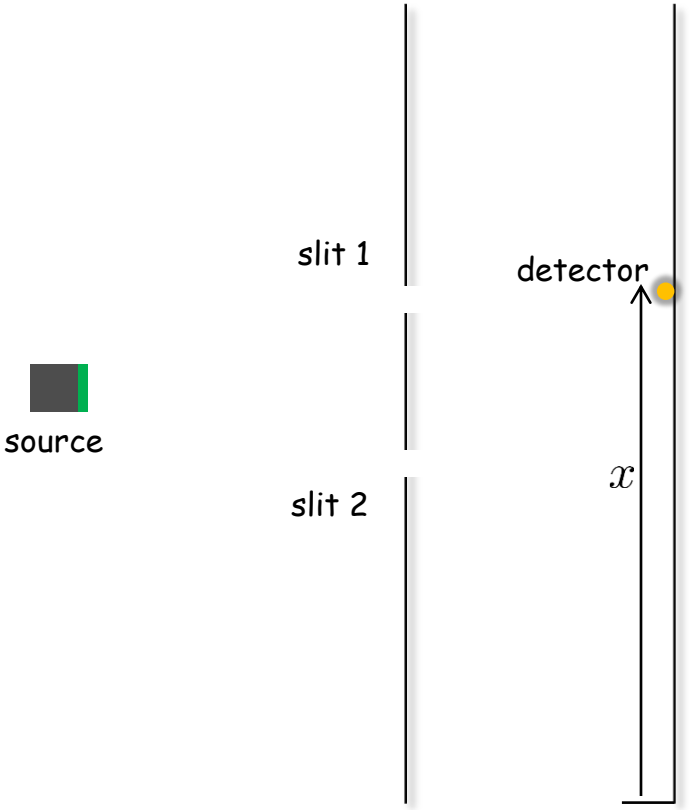


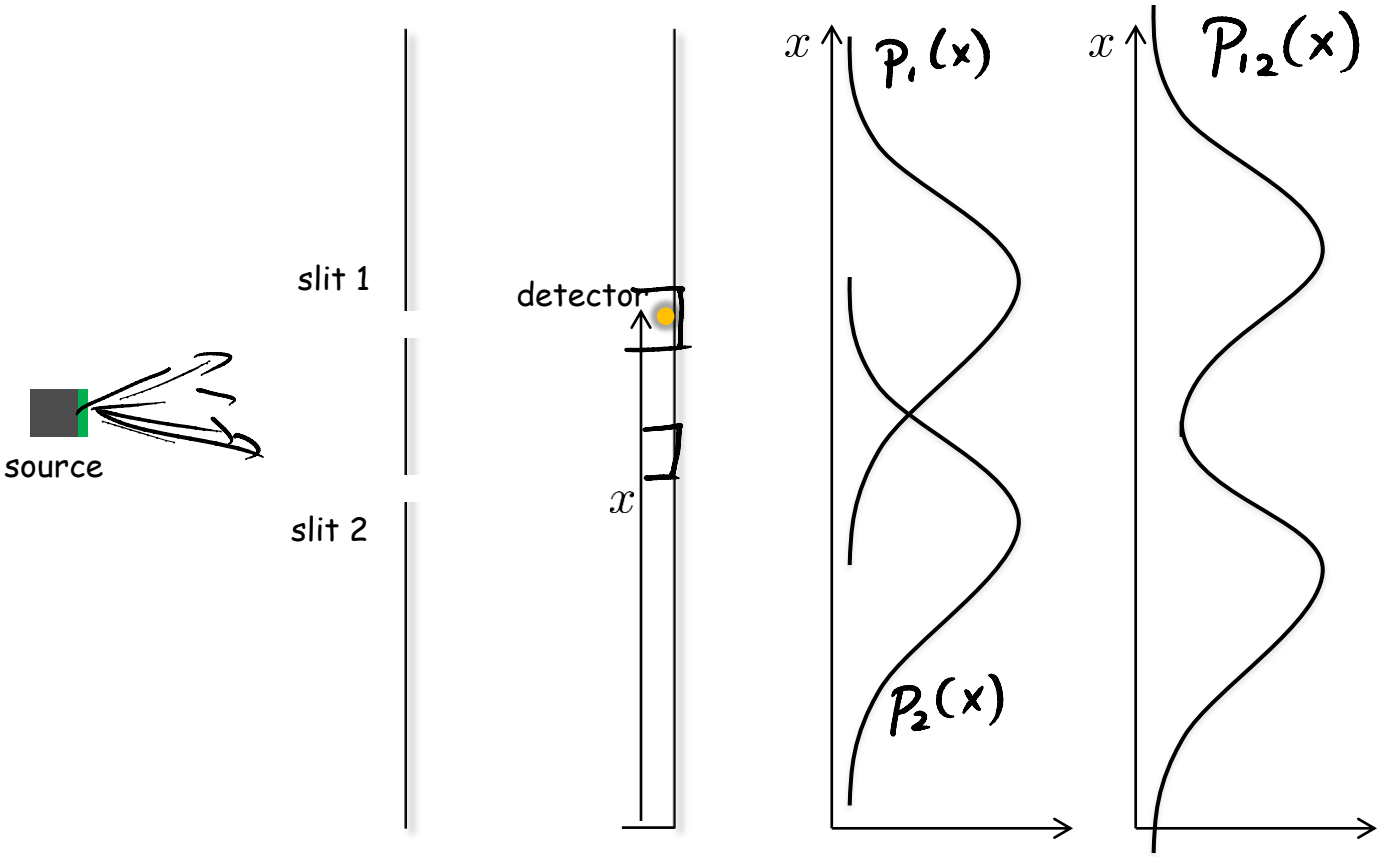
electrons / photons

bullets

water waves

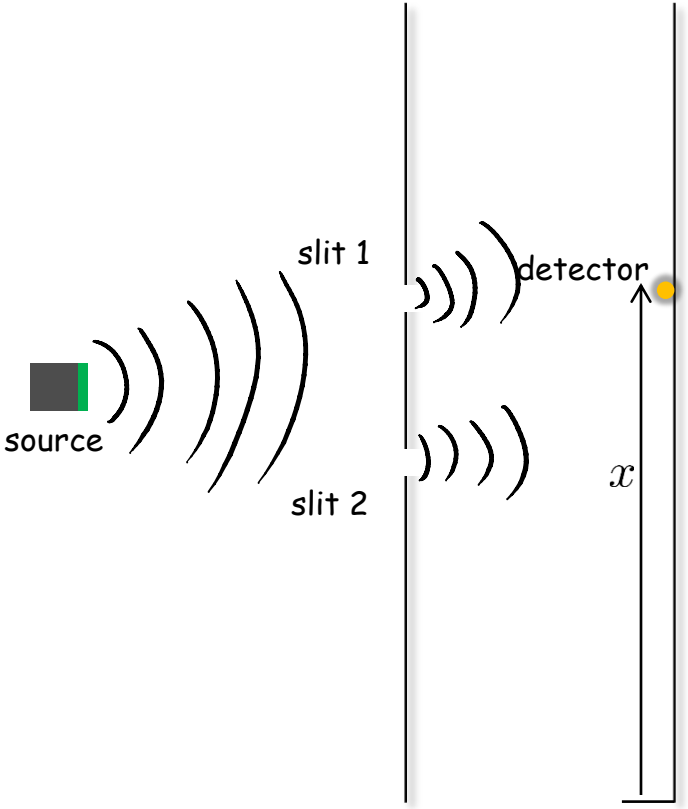
Double-slit experiment

Bullets



Double-slit experiment

Waves



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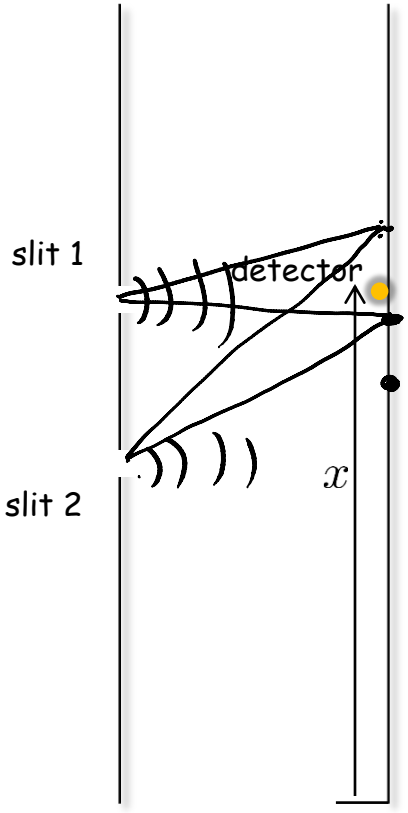
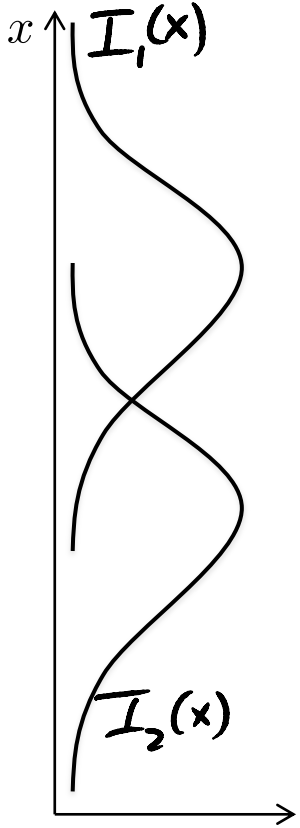
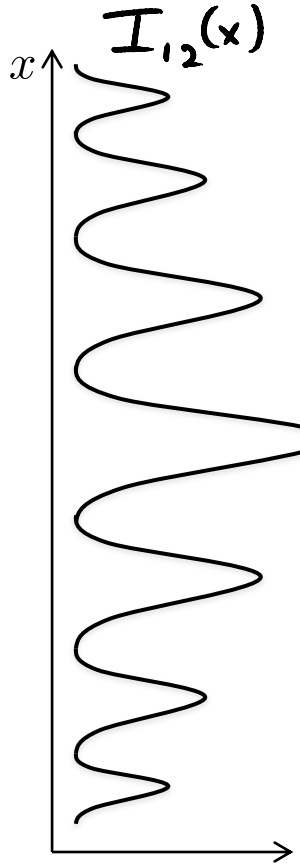


Waves





$I_{12}(x) \neq I_1(x) + I_2(x)$

$I(x) = h(x)^2$

$h_{12}(x) = h_1(x) + h_2(x)$

$I_{12}(x) = h_{12}(x)^2$

$h_1(x)^2 + h_2(x)^2$

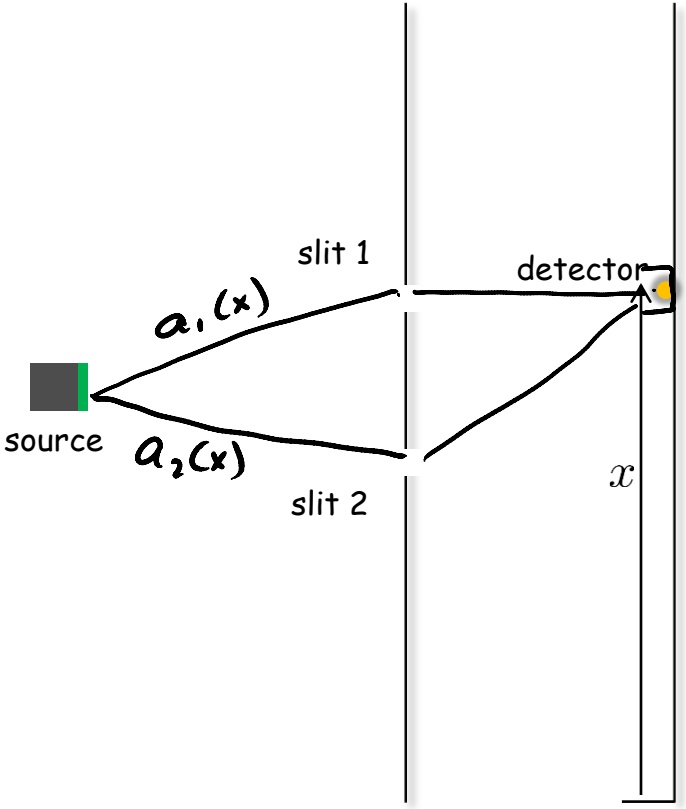
$\| \quad \|$

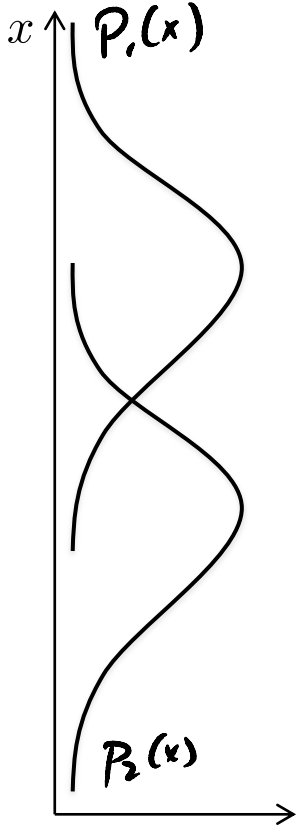
$I_1(x) \quad I_2(x)$

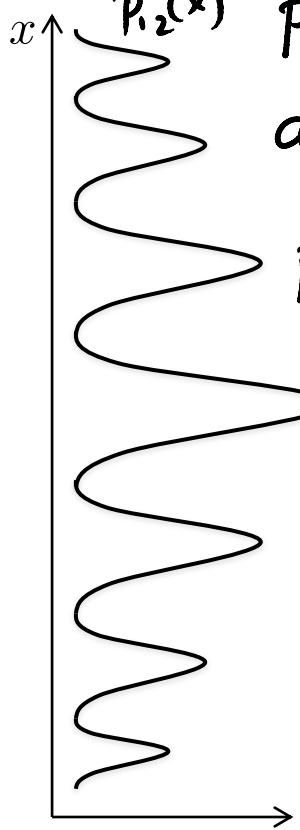
Double-slit experiment

Electrons/Photons

$P_{12}(x) \neq P_1(x) + P_2(x)$







$P(x) = a(x)^2$

$a_{12}(x) = a_1(x) + a_2(x)$

$P_{12}(x) = a_{12}(x)^2$

$\neq$

$a_1(x)^2 + a_2(x)^2$

$\| \qquad \|$

$P_1(x) \qquad P_2(x)$

- If we want to describe what happens in an atomic event, we have to realize that the word "happens" can only apply to the observation, not to the state of affairs between two observations.

Heisenberg (1958)

- Do not keep saying to yourself, if you can possibly avoid it, 'But how can it possibly be like that?' because you will go down the drain into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that.

Feynman (1965)

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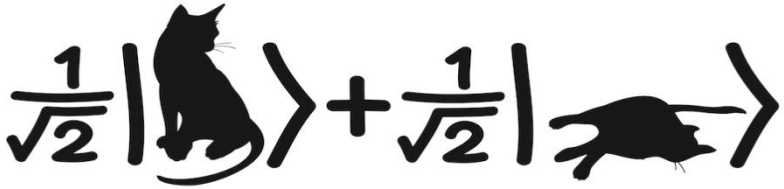

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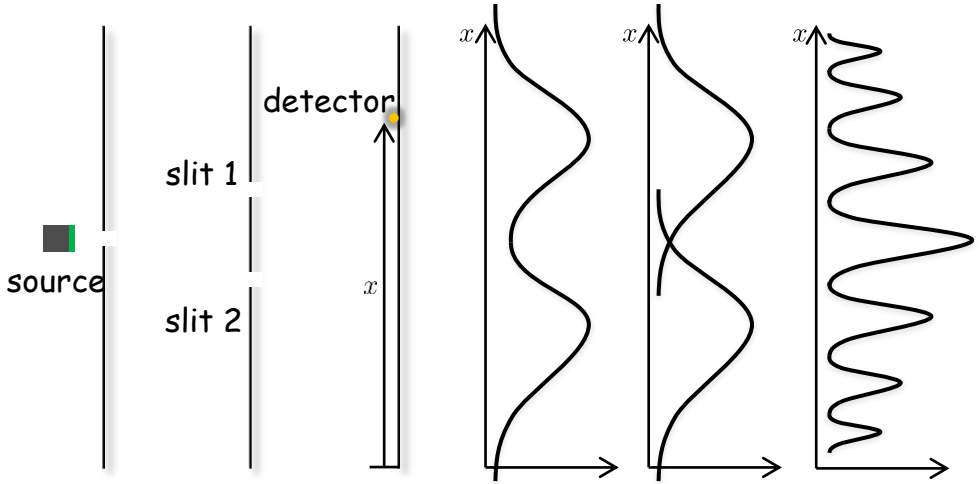


$$I_1(x) = h_1(x)^2$$
$$I_2(x) = h_2(x)^2$$
$$h_{12}(x) = h_1(x) + h_2(x)$$
$$I_{12} = h_{12}^2 = (h_1(x) + h_2(x))^2$$

$$P_1(x) = |a_1(x)|^2$$
$$P_2(x) = |a_2(x)|^2$$
$$a_{12}(x) = a_1(x) + a_2(x)$$

Bullets
Discrete
Prob arrival
$P_{12} = P_1 + P_2$
No interference

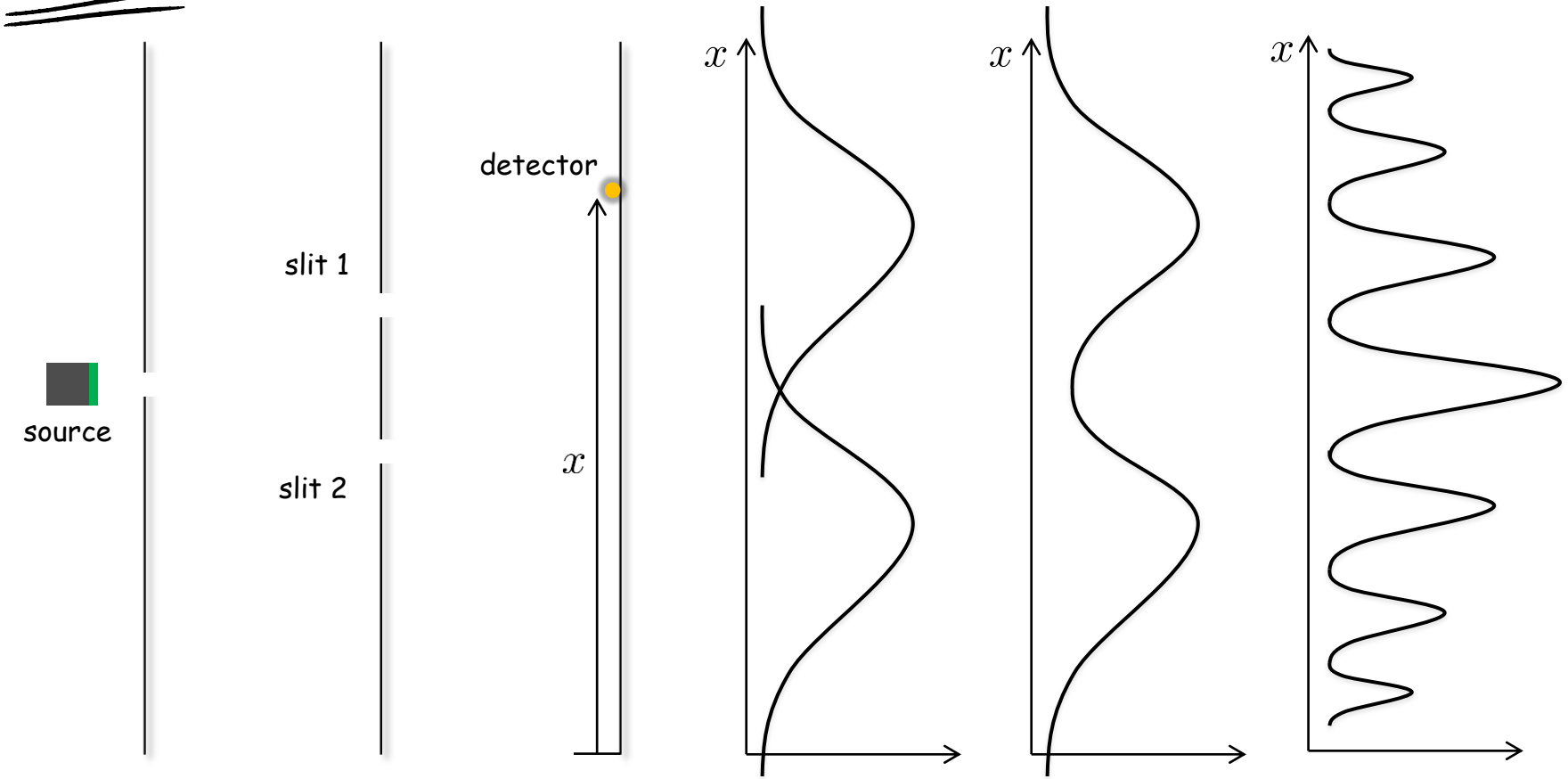
Water Waves
Continuous
Intensity
$I_{12} \neq I_1 + I_2$
Interference.

Photons/Electrons.
Discrete
Prob of arrival.
$P_{12} \neq P_1 + P_2$
Interference.

Proposition: The electron went through slit 1 or it went through slit 2.

Proposition: The electron went through slit 1 or it went through slit 2.

Test



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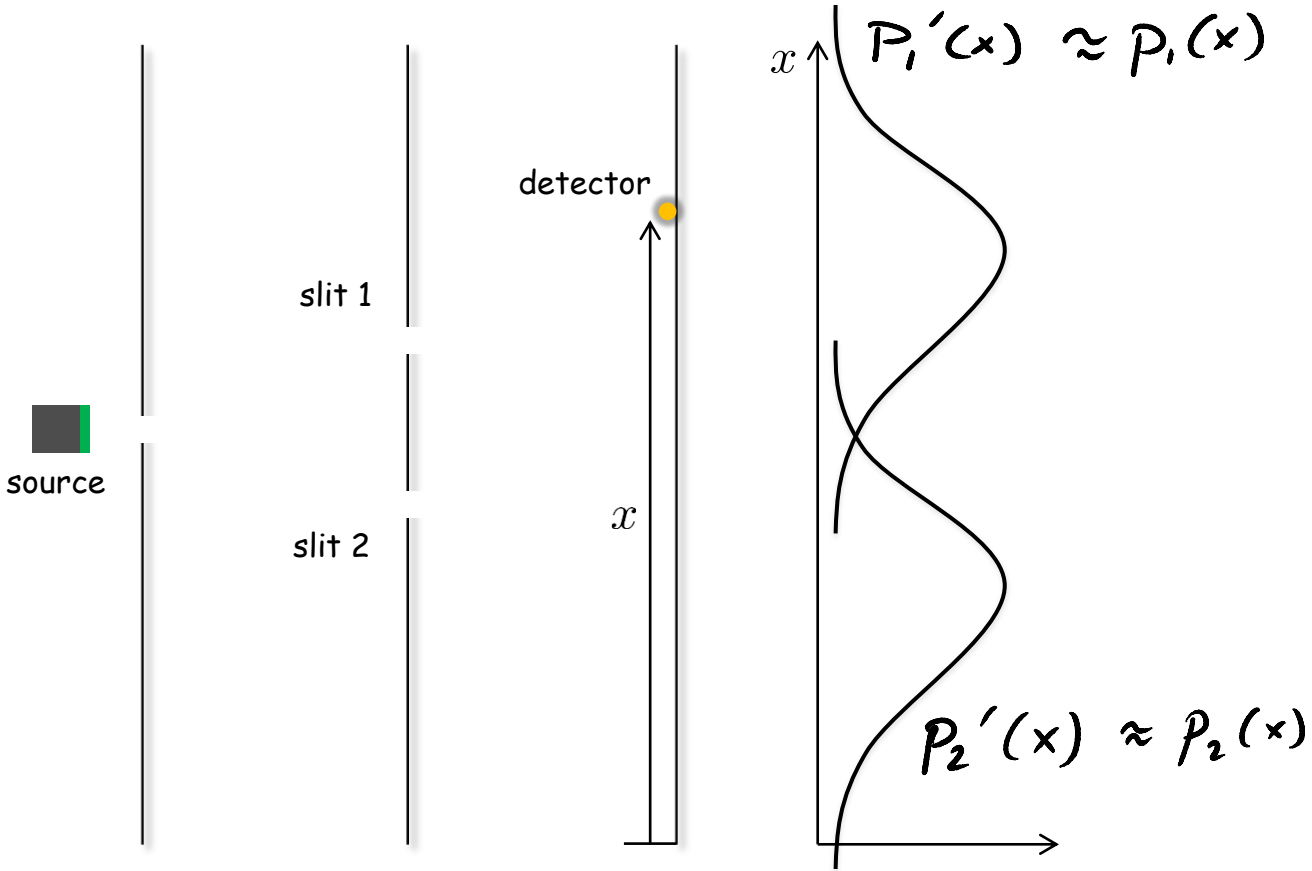

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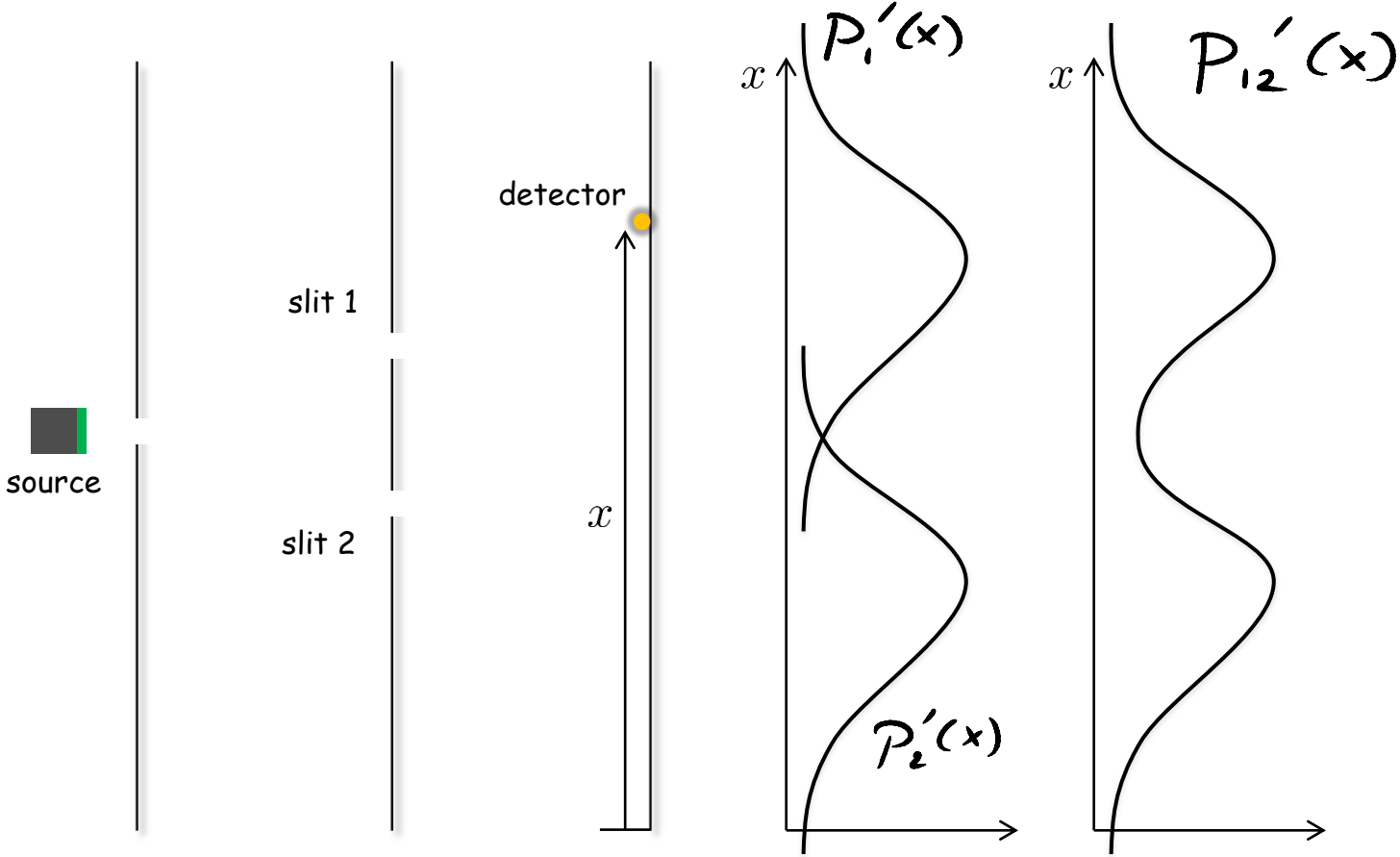

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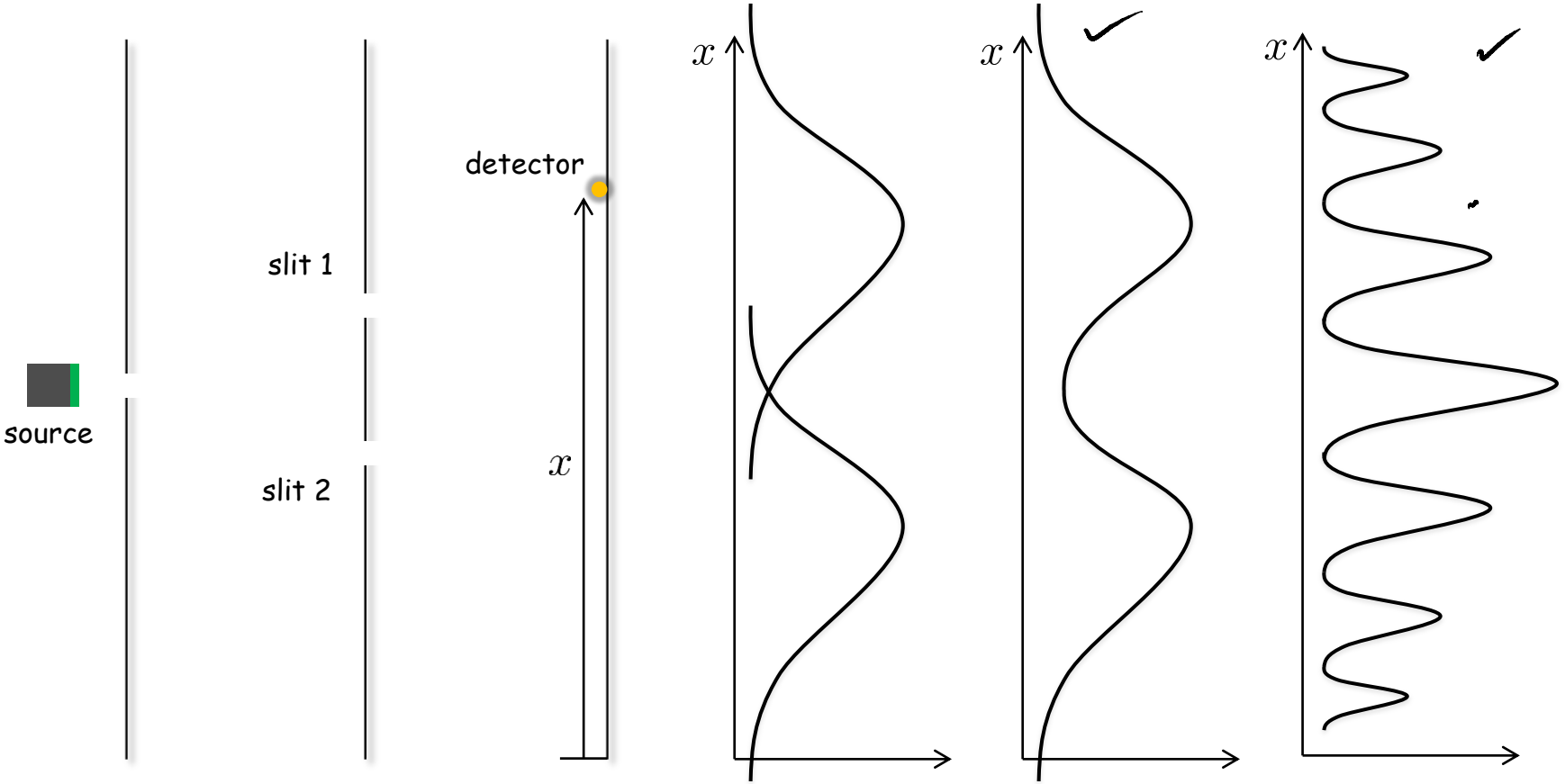

Heisenberg's Uncertainty Principle

- An electron is delicate.
- Measurement disturbs system.
- Make light fainter:
  - But light is quantized
- Heisenberg's Uncertainty Principle: impossible to design apparatus that detects which slit without disturbing interference pattern.

Probability inherent in QM: suppose you could predict which slit the electron will go through: