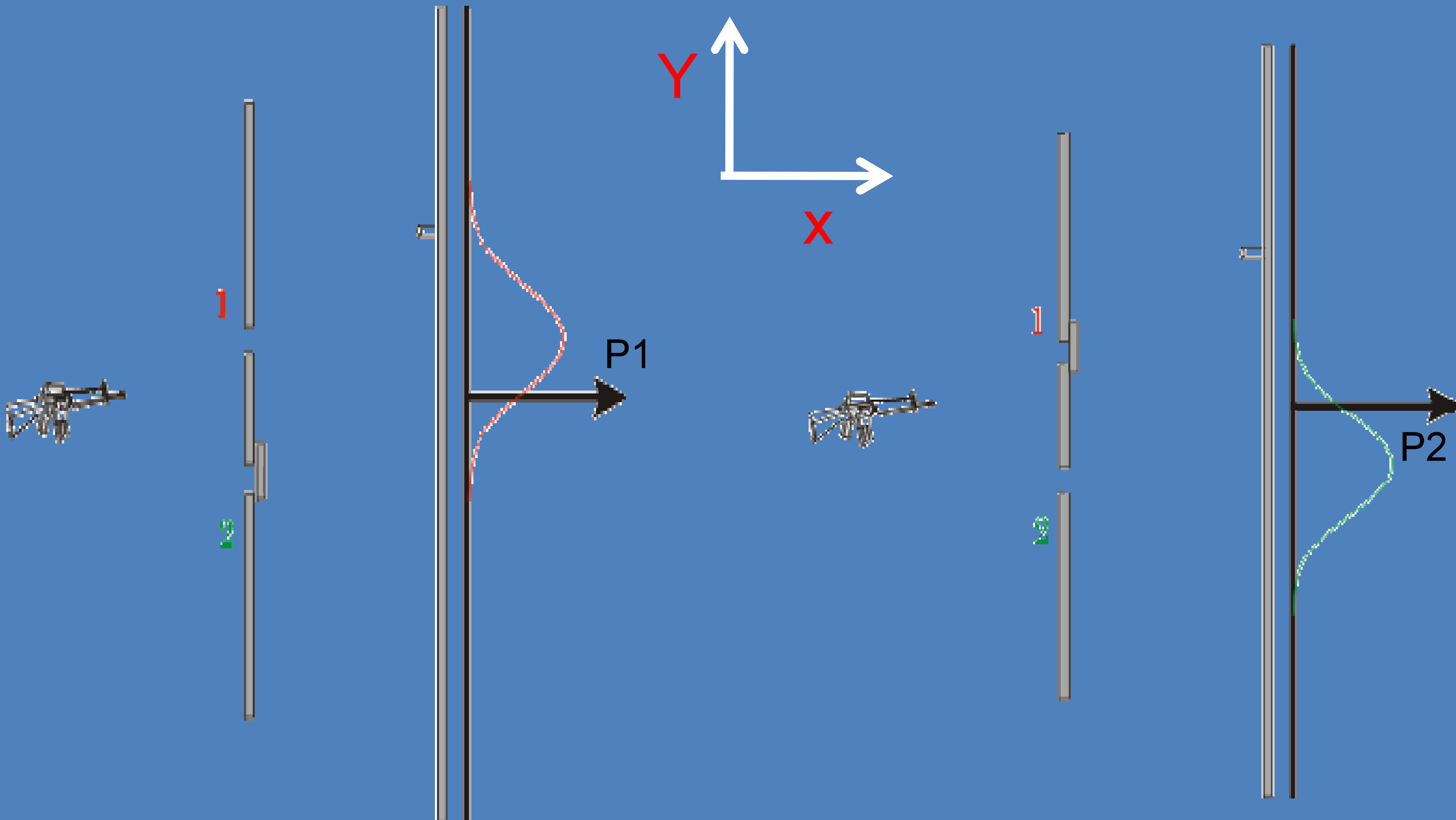
Light: A Particle or Wave

- Different tests support different sides of the argument
- Today: dual theory
- Young Experiment

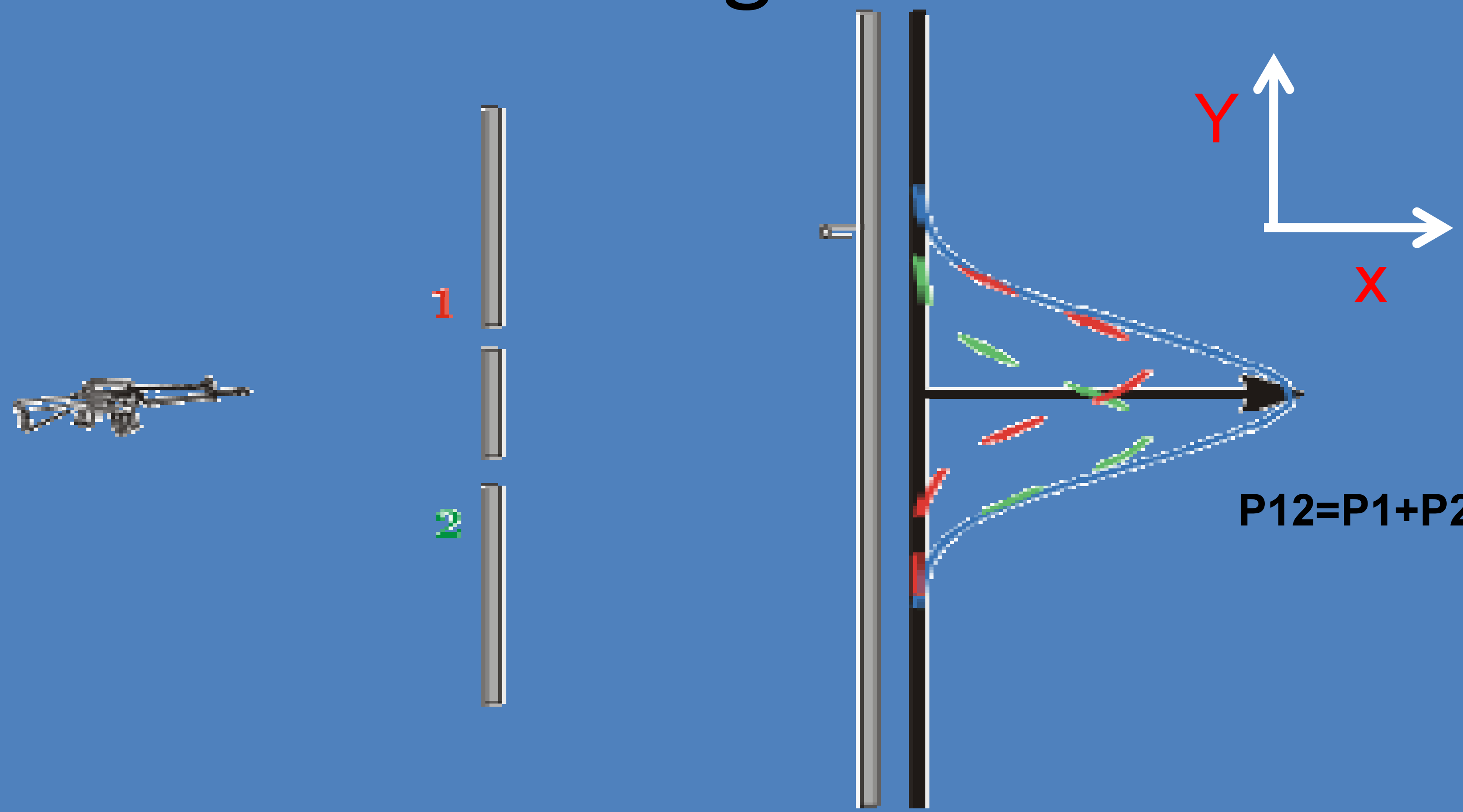
2-slit experiments with bullets (Particles)

- Bullets always come in "lumps" -- identical size, mass, particles.



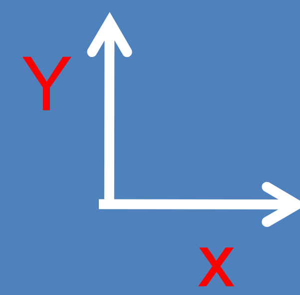
“God does not play dice with the universe.”
— Albert Einstein

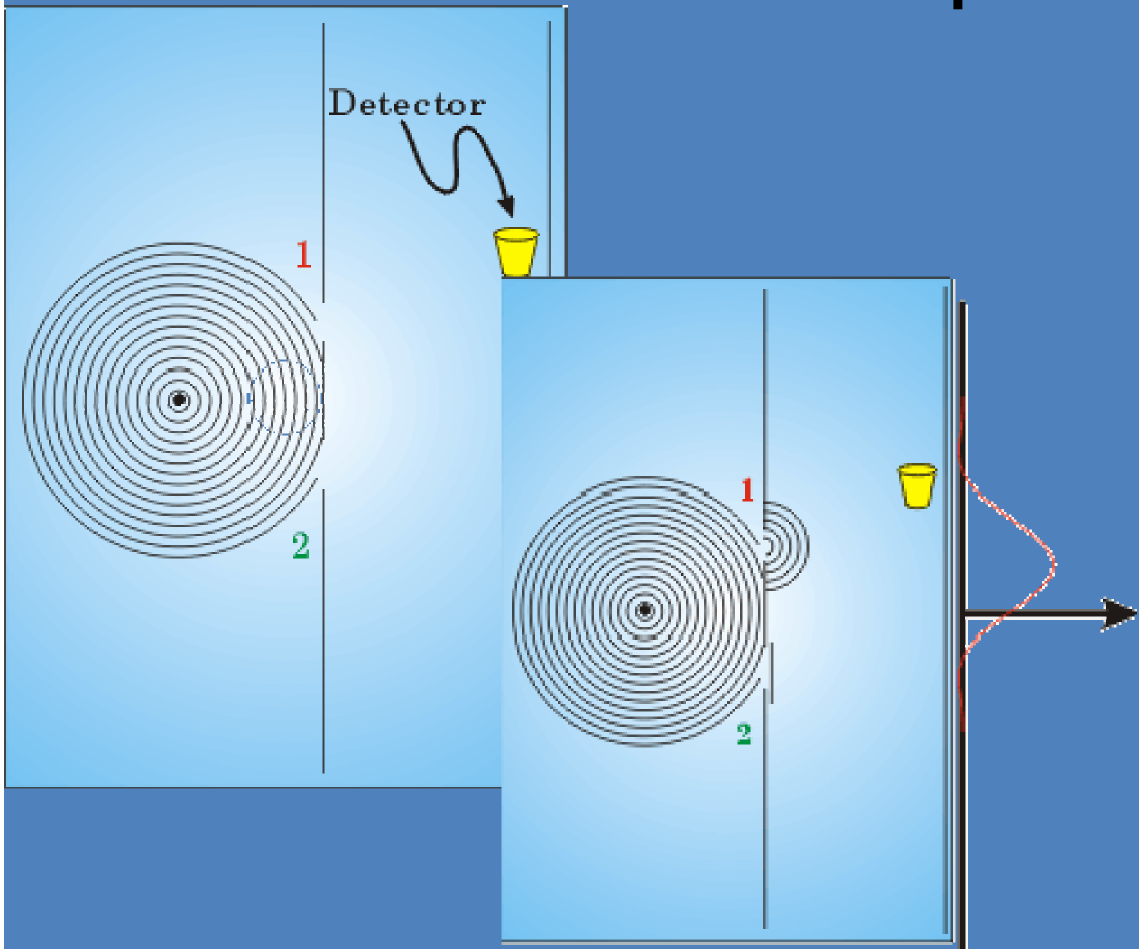
Particles Through Both Slits



No interference: Probability to arrive at screen is sum of probability to go through slit 1 and probability to go through slit 2, smooth distribution.

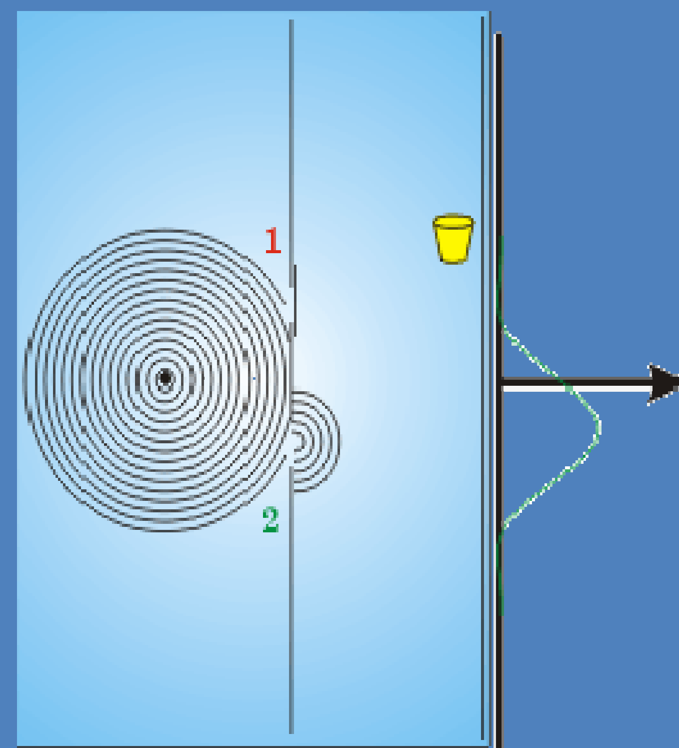
2-slit experiments with water (waves)





When 1st Slit open

$I_1=|h1|^2$

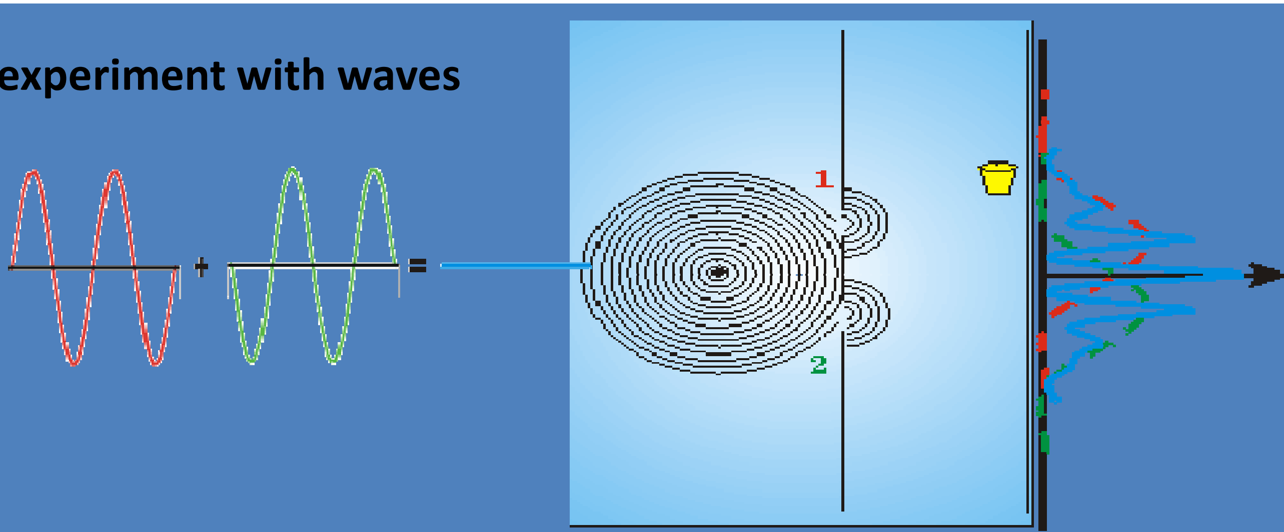


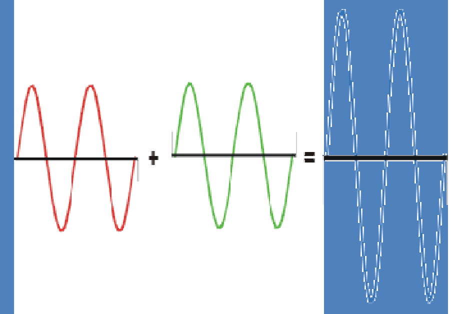
When 2nd Slit open

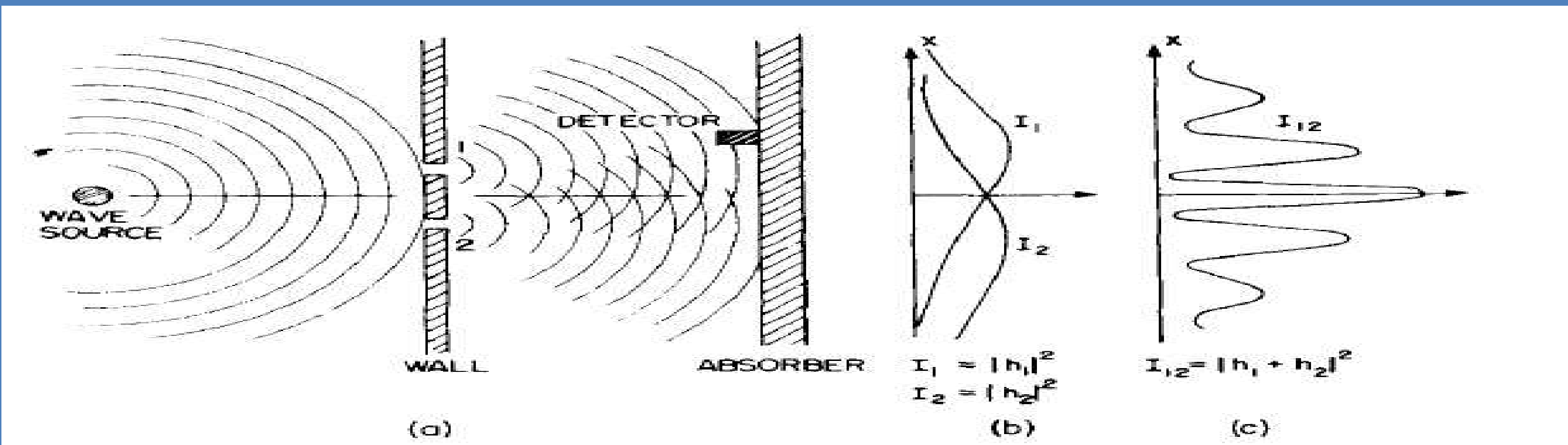
$I_2=|h2|^2$

- Intensity of water waves proportional to height 2.

An experiment with waves





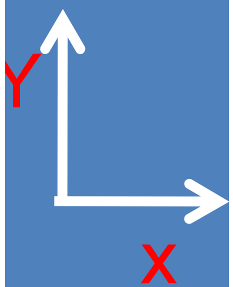


$$I_1 = |h_1|^2, \qquad I_2 = |h_2|^2, \qquad I_{12} = |h_1 + h_2|^2.$$

$$I_{12} = I_1 + I_2 + 2\sqrt{I_1 I_2}\cos\delta.$$

where δ is the phase difference between h_1 and h_2

2-slit experiments with Electrons



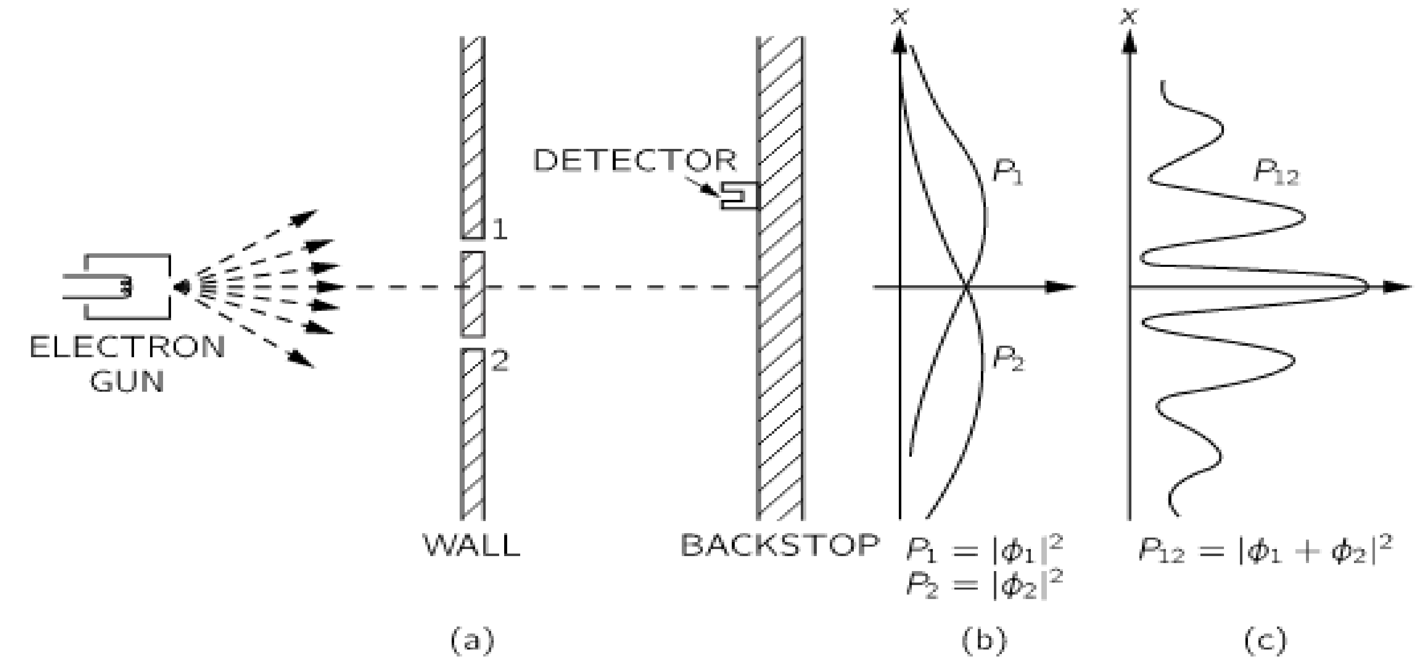


Fig. 1–3. Interference experiment with electrons.

“What is the relative probability that an electron ‘lump’ will arrive at the backstop at various distances *x* from the center?”

The result of our experiment is the interesting curve marked *P*12 in part (c). This is the way electrons go.

Proposition A: **Each electron *either* goes through hole 1 *or* it goes through hole 2.**

The result P_{12} obtained with both holes open is Clearly not the sum of P_1 and P_2, the probabilities for Each hole alone. *In* analogy with our water wave experiment, we say, "There is interference"

For electrons: $$P_{12} \neq P_1 + P_2.$$

We conclude the following: The electrons arrive in lumps, like particles, and the probability of arrival of these lumps is distributed like the distribution of intensity of a wave. It is in this sense that an electron behaves "sometimes like a particle and sometimes like a wave."

As we would have concluded from **Proposition A**, undoubtedly we should conclude that ***Proposition A is false***. It is *not* true that the electrons go *either* through hole 1 or hole 2. But that conclusion can be tested by another experiment.

if electrons can be seen to go through one slit or the other, how can they interfere with themselves? Let's try to determine which slit they pass through with a "camera"

Watching the electrons

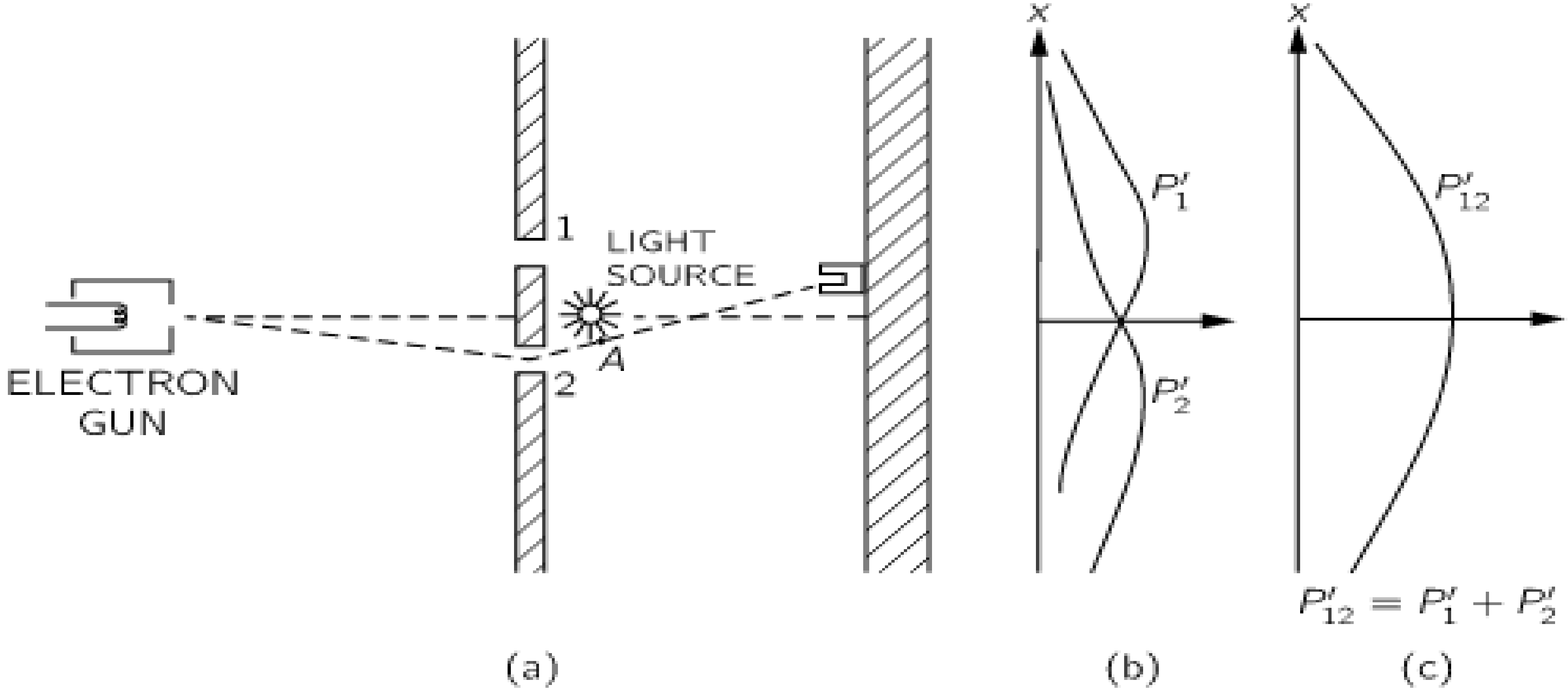


Fig. 1–4. A different electron experiment.

If the motion of all matter—as well as electrons—must be described in terms of waves, what about the bullets in our first experiment? **Why didn't we see an interference pattern there?**

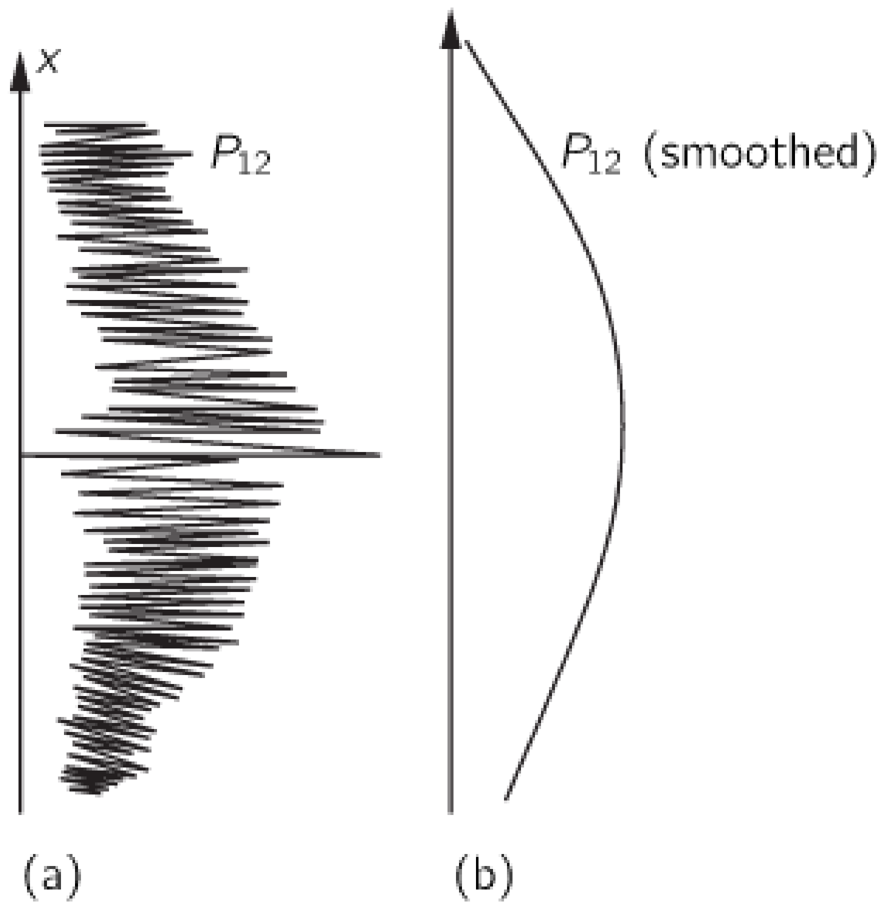


Fig. 1–5. Interference pattern with bullets: (a) actual (schematic), (b) observed.

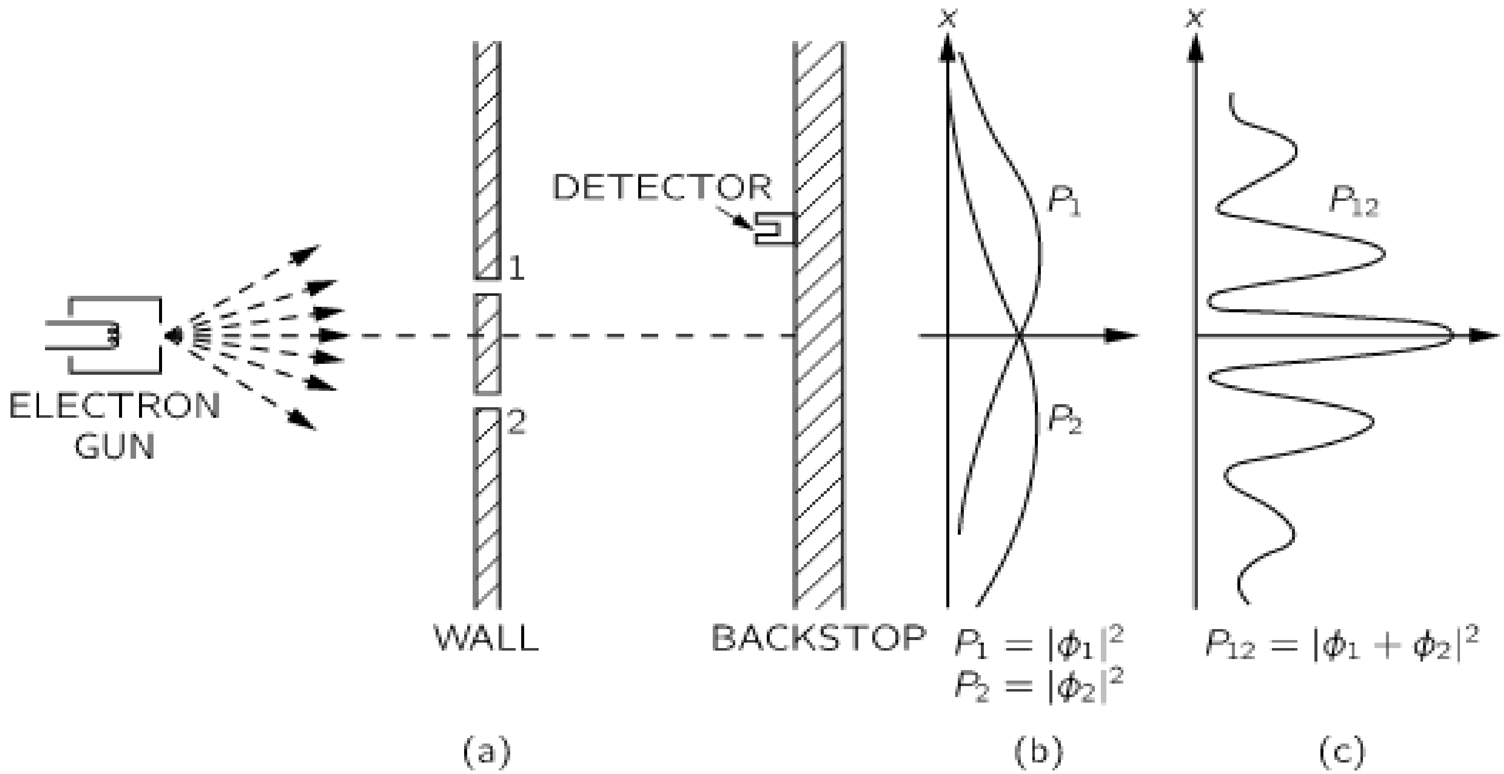


Fig. 1–3. Interference experiment with electrons.

First principles of quantum mechanics

(1) The probability of an event in an ideal experiment is given by the square of the absolute value of a complex number ϕ which is called the probability amplitude:

P = probability

Φ = probability amplitude

$$P = |\phi|^2$$

(2) When an event can occur in several alternative ways, the probability amplitude for the event is the sum of the probability amplitudes for each way considered separately. There is interference:

$$\phi = \phi_1 + \phi_2$$

$$P = |\phi_1 + \phi_2|^2$$

(3) If an experiment is performed which is capable of determining whether one or another alternative is actually taken, the probability of the event is the sum of the probabilities for each alternative. The interference is lost:

$$P = P_1 + P_2 = |\phi_1|^2 + |\phi_2|^2$$