Title: Quantum Theory Lecture - 090623

Speakers: Bindiya Arora, Dan Wohns

Collection: Quantum Theory 2023/24

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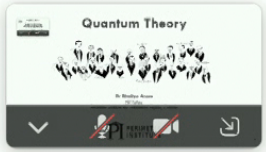

Quantum Theory

Dr Bindiya Arora

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Perimeter Institute for Theoretical Physics, Canada

PERIMETER INSTITUTE

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Introduction

Name: Bindiya Arora (*Arora or Bindiya*)

(Phonetic spelling of Bindiya: b-ih-n-d-ee-y-ah Rhymes with India)

Office: 265

Email: barora@perimeterinstitute.ca

Office Hours: by email or email to arrange for a meeting

Teaching Assistant: Sercan Husnugil

Second Half: Introduction to scalar quantum field theory, The Feynman diagram technique for perturbation theory

Information on PSI Portal: tentative schedule, references

Course Requirements

- Complete all quizzes
- **Attend and participate in all tutorials.** You do not need to submit your tutorial work if you participate in the live session
- **Submit correct solutions to all homework problems.** Homework solutions should be submitted electronically via the link on the course website
- Demonstrate an understanding of key concepts and an ability to perform basic calculations in an interview

Homework Policy

- There will be three deadlines spaced approximately two weeks apart
- No extensions are possible for the first two deadlines
  Extensions with valid reasons are possible for the final deadline.
- Will receive feedback after the first and second deadline

Course Objective

We shall try to build **foundation** for subsequent courses

Quantum Theory

Quantum Foundation

Quantum Information

Quantum Field Theory

2 Second Lecture

Arrow of Time

- Schrodinger vs Heisenberg
- Quantum Revivals
- Bloch Sphere

3 Third Lecture

Time Dependent Potentials

- Interaction Picture
- Fermi Golden Rule
- Rabi Oscillations

4 Fourth Lecture

Working With Ensembles

- Density Matrix
- Measurement & Decoherence
- Composite Systems

5 Fifth Lecture

Which Way? Why This Way?

- Path Integral Formalism
- Classical vs Quantum
- How to Interpret

6 Sixth Lecture

From Particles to Fields

- Field (Scalar)
- Bunch of Oscillators
- Propagating Disturbances

7 Seventh Lecture

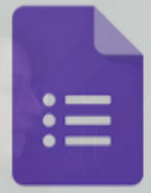
From Fields to Particles

- Birth of Particles
- Interactions & Yukawa's Hypothesis
- Perturbative Field Theory

*Special thanks to Vipul for help in developing the course content, animations and visualisations

Ask Station

slido



Google Forms

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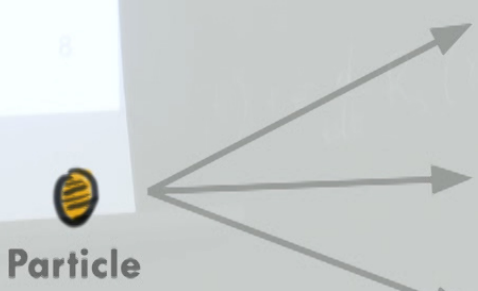
Observations



Particles hit screen at **Random Positions** = **No pattern in trajectory**

However we find pattern in the **Probabilities**

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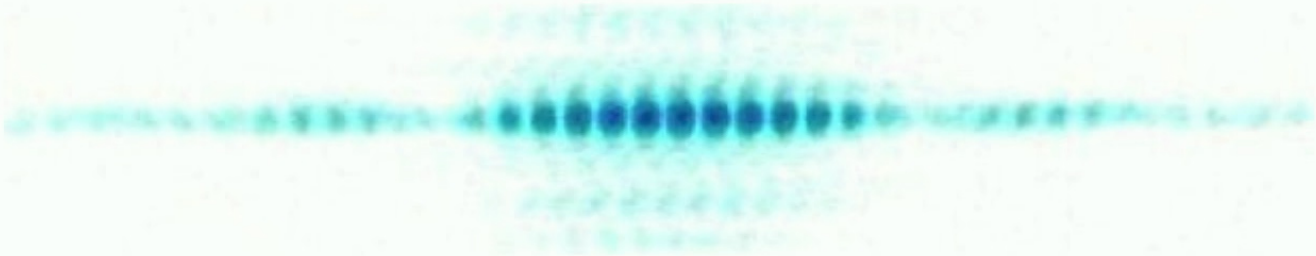
"the double-slit experiment has in it the heart of quantum mechanics. In reality, it contains the only mystery"

Richard P. Feynman

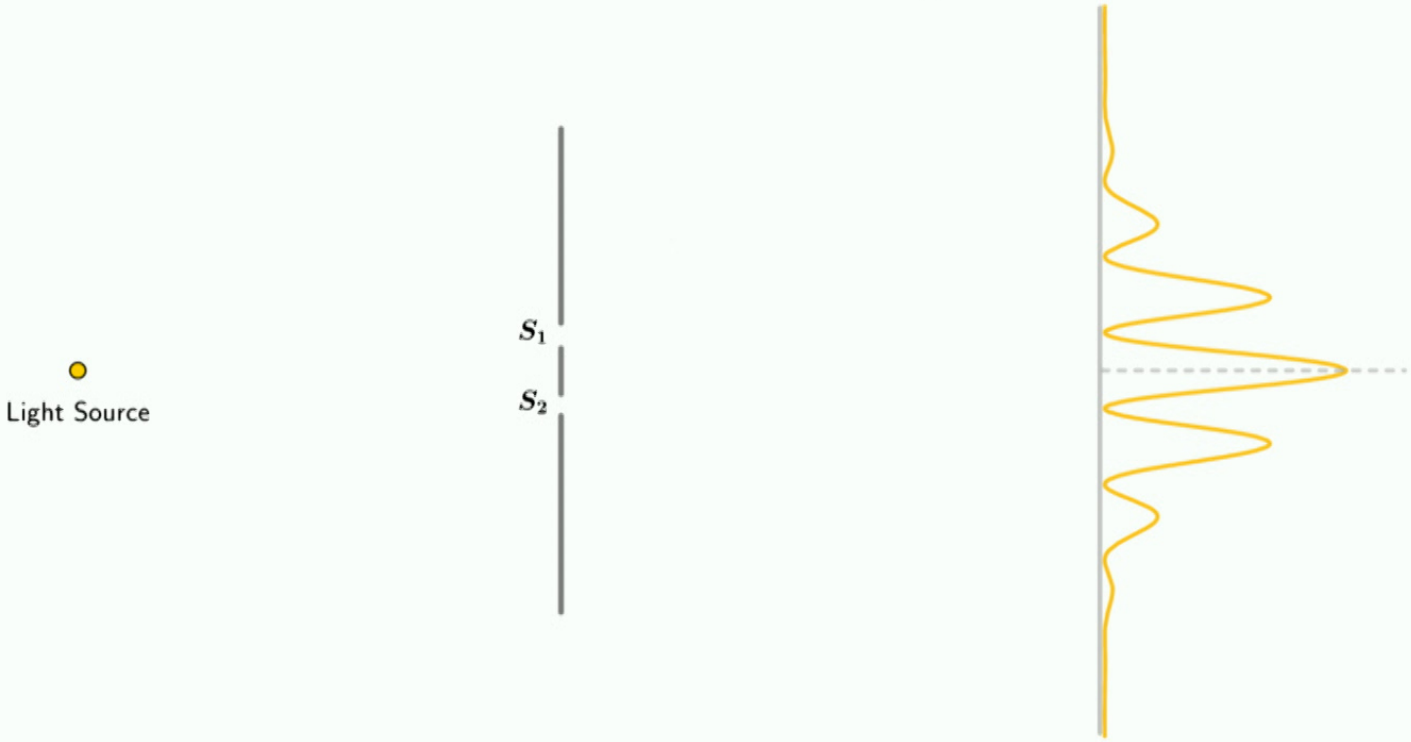
Double-slit experiment

First performed by Thomas Young in 1801

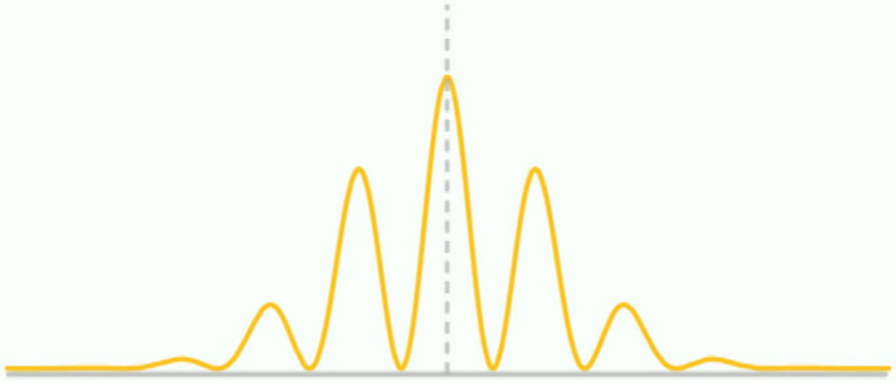


A Do-It-Yourself QUANTUM ERASER

A Quick Recap



Hillmer R, Kwiat P. A do-it-yourself quantum eraser. Sci Am. 2007 May;296(5):90-5.
Doi: 10.1038/scientificamerican0507-90. PMID: 17500419.



Double-Slit

Single-Slit

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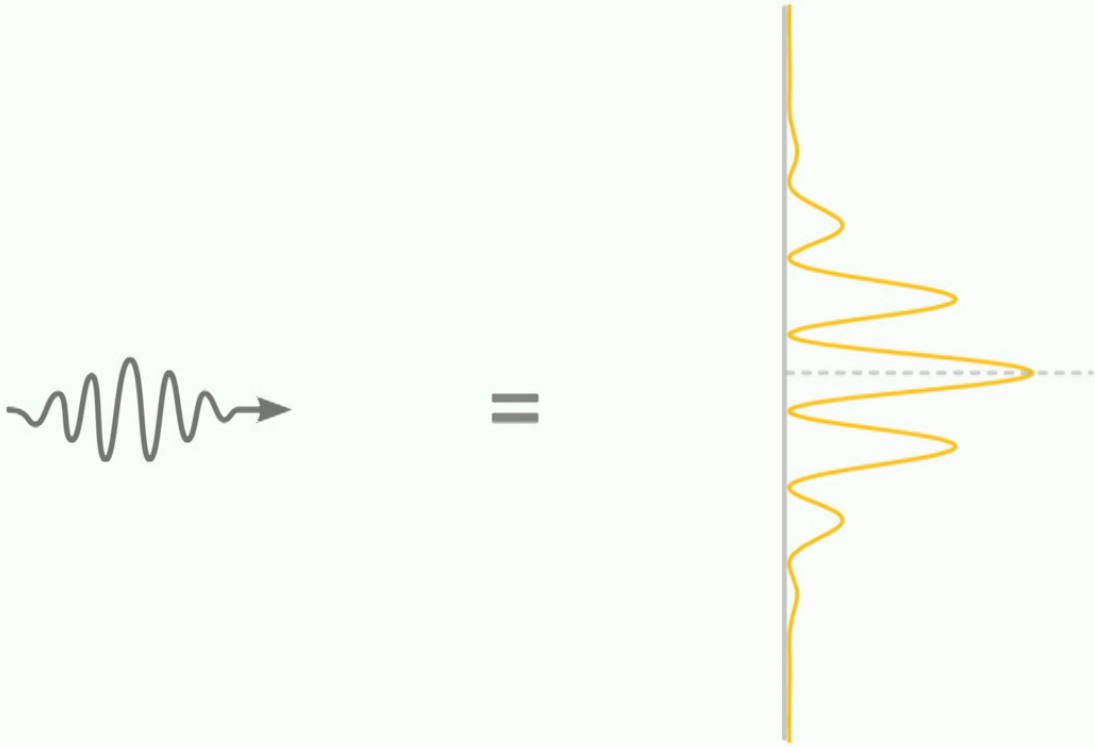
Possible Interpretations

- Each particle passes through one of the two slits and interacts with other particles

- Each particle interacts with both slits



We get interference pattern even if we pass only **one particle** at a time through the apparatus

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Superposition

$$|\psi\rangle = |\psi\rangle_{s_1} + |\psi\rangle_{s_2}$$

Does the particle pass through both of the slits ?

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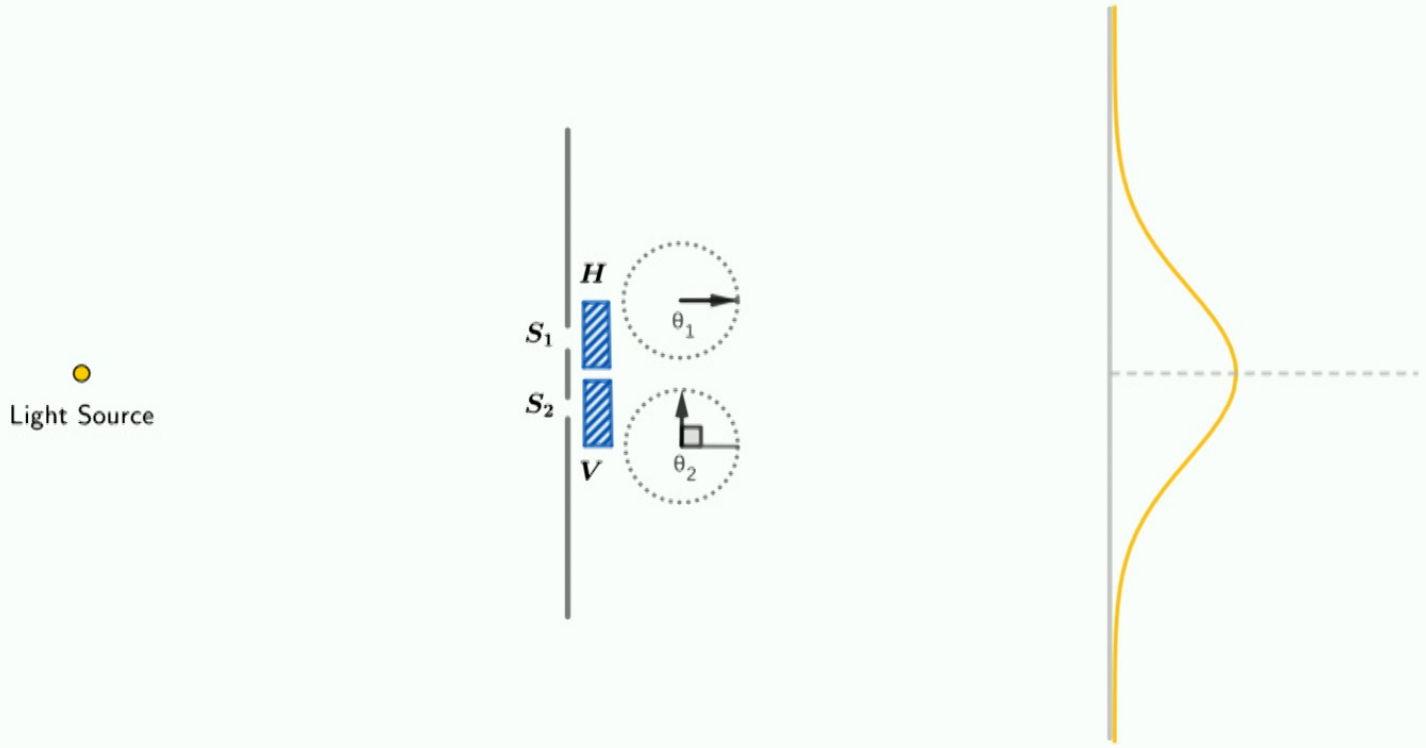
The Which Way Information

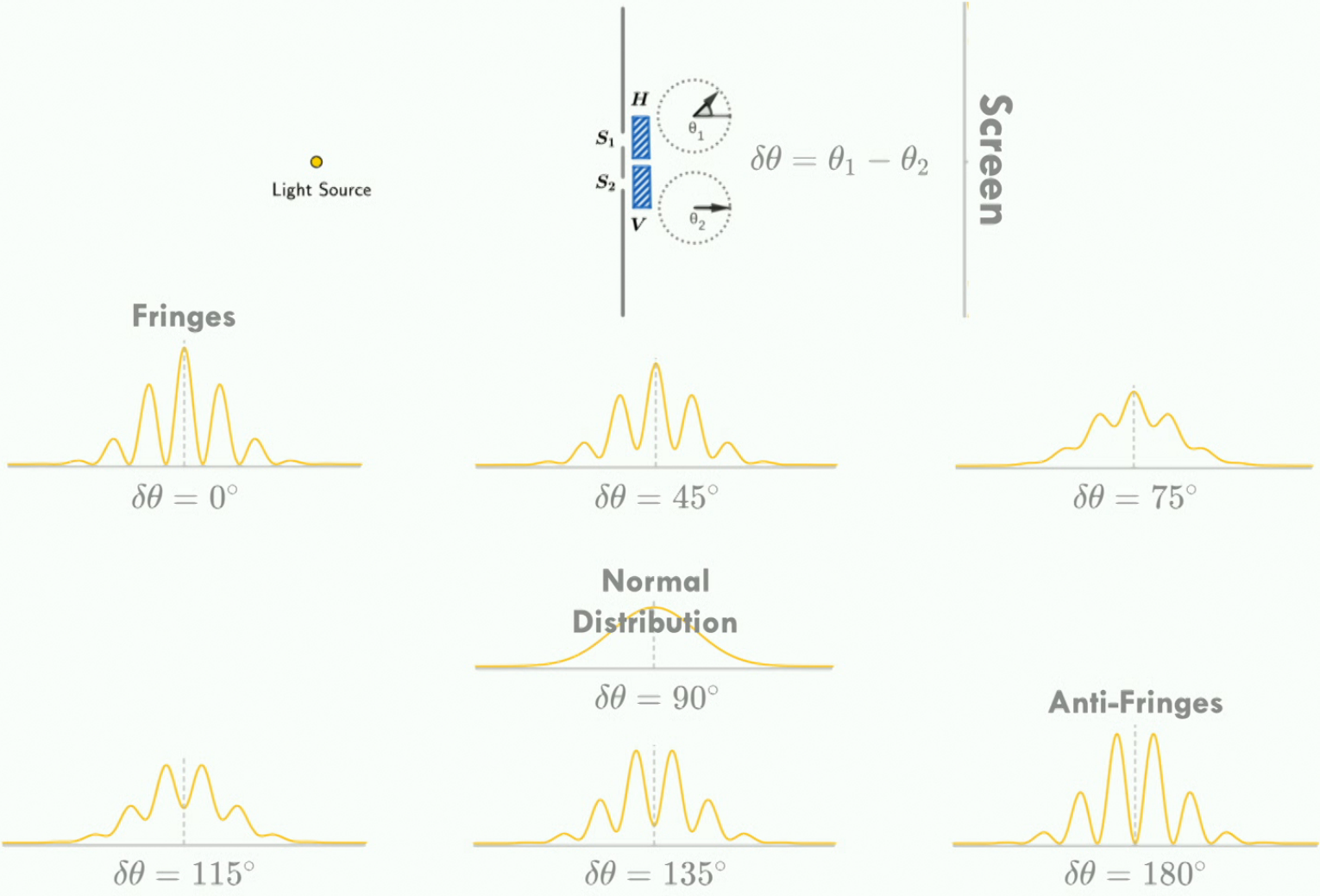
When we mark slits with a horizontal and a vertical polarizer the pattern disappears



Marking States

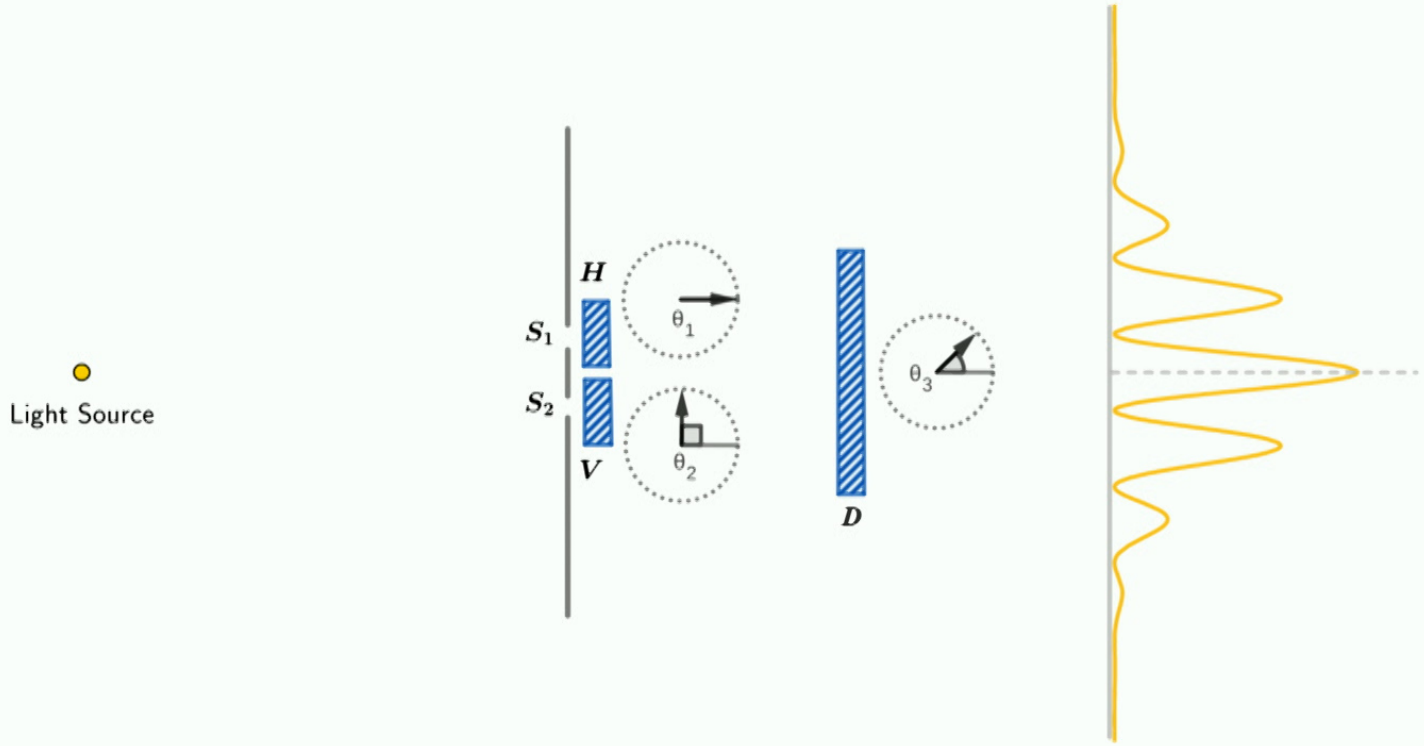
$$|\psi\rangle = \frac{|\psi\rangle_{s_1}|H\rangle + |\psi\rangle_{s_2}|V\rangle}{\sqrt{2}}$$

where $|H\rangle = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$ and $|V\rangle = \begin{bmatrix} 0 \\ 1 \end{bmatrix}$


Light Source
H
S1
S2
V
θ1
θ2
δθ = θ1 − θ2
Screen
Fringes
δθ = 0°
δθ = 45°
δθ = 75°
Normal Distribution
δθ = 90°
Anti-Fringes
δθ = 115°
δθ = 135°
δθ = 180°

Quantum Erasers

If we erase the which information using a third polarizer at 45° the pattern reappears



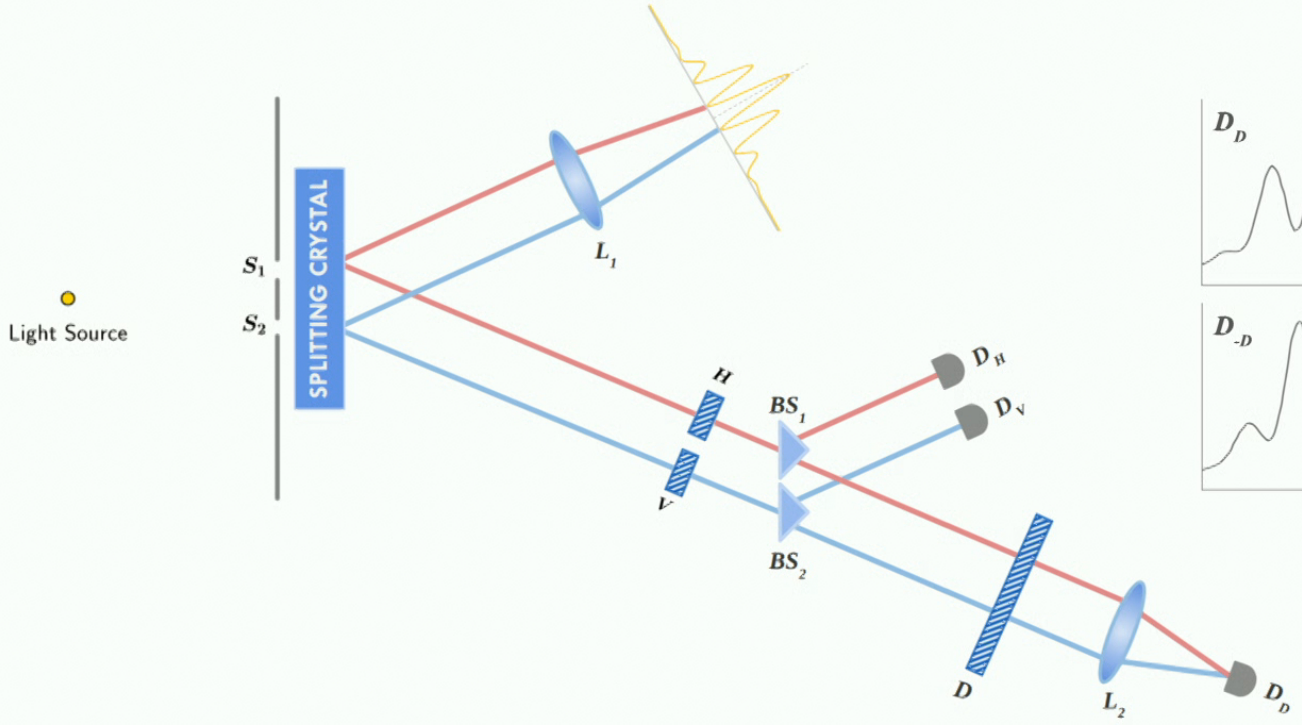
Eraser

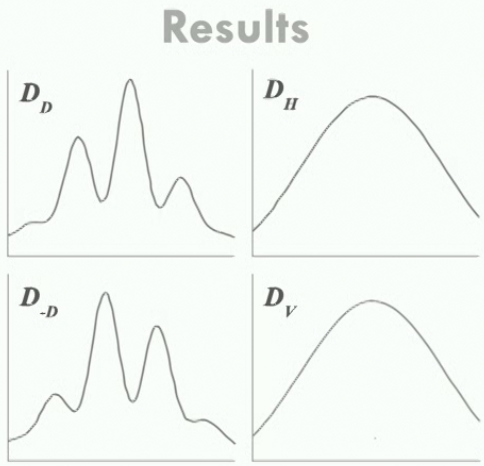
$$|\psi\rangle = \frac{|\psi\rangle_{s_1}\langle D|H\rangle + |\psi\rangle_{s_2}\langle D|V\rangle}{\sqrt{2}}$$

$$\text{where} \quad |D\rangle = \frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$$

Delayed Choice

Even if we want our eraser to act after photon hits the screen, still pattern reappears





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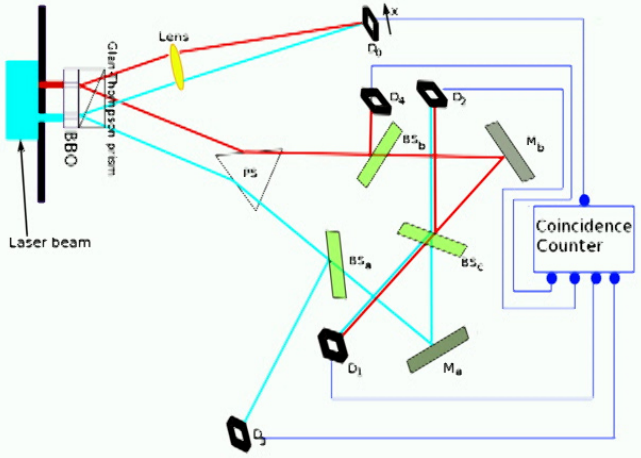
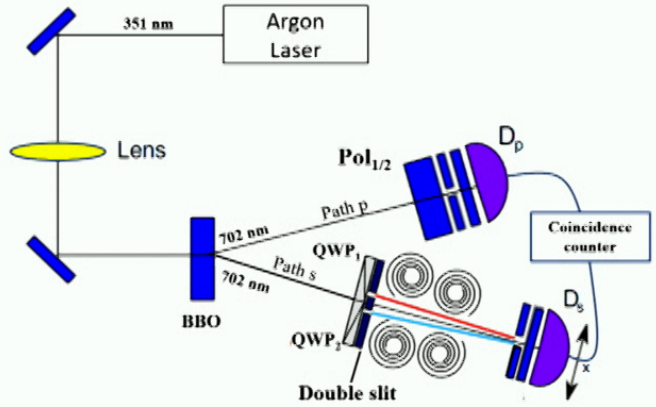
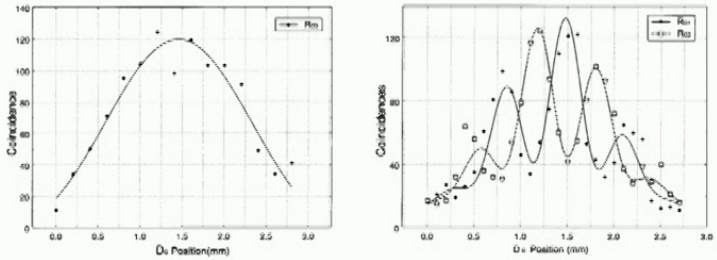
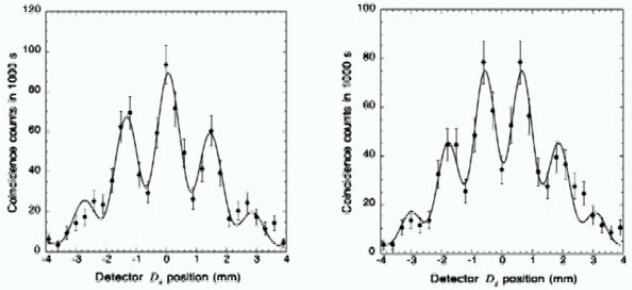
Delayed Choice Quantum Eraser Experimental Setups









Kim, Yoon-Ho; R. Yu; S. P. Kulik; Y. H. Shih; Marlan Scully (2000). "A Delayed "Choice" Quantum Eraser". Physical Review Letters. 84 (1), 1–5

S. P. Walborn, M. O. Terra Cunha, S. Pádua, and C. H. Monken (2002), "Double-slit quantum eraser," Phys. Rev. A 65, 033818.

Interpretations

*The act of measurement can affect a particle's behavior, and this influence can manifest **retroactively***

Realist

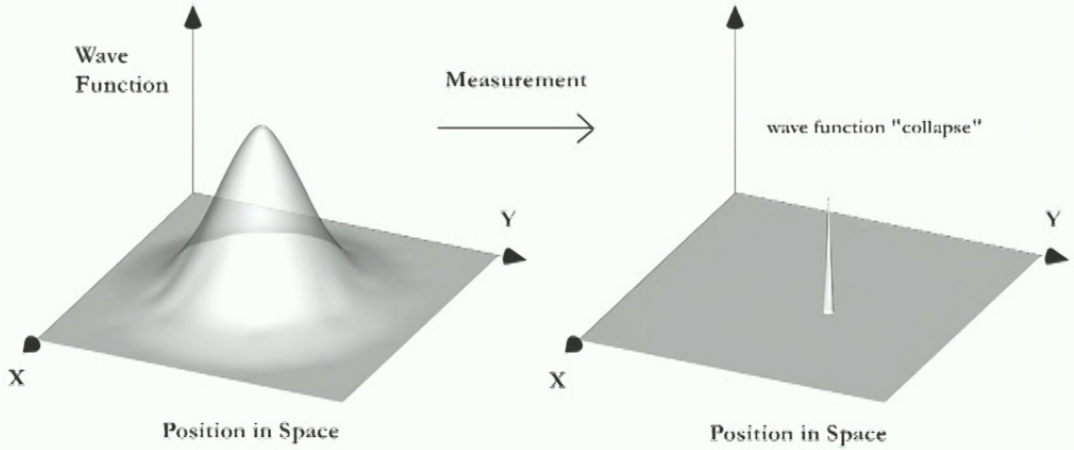
- The particle was there
- The uncertainty reflects our ignorance, some additional information (**hidden variable**) is needed

Orthodox

- The particle wasn't really anywhere
- The act of observation not only affects the measured quantity, but it actively brings it into existence (**copenhagen interpretations**)

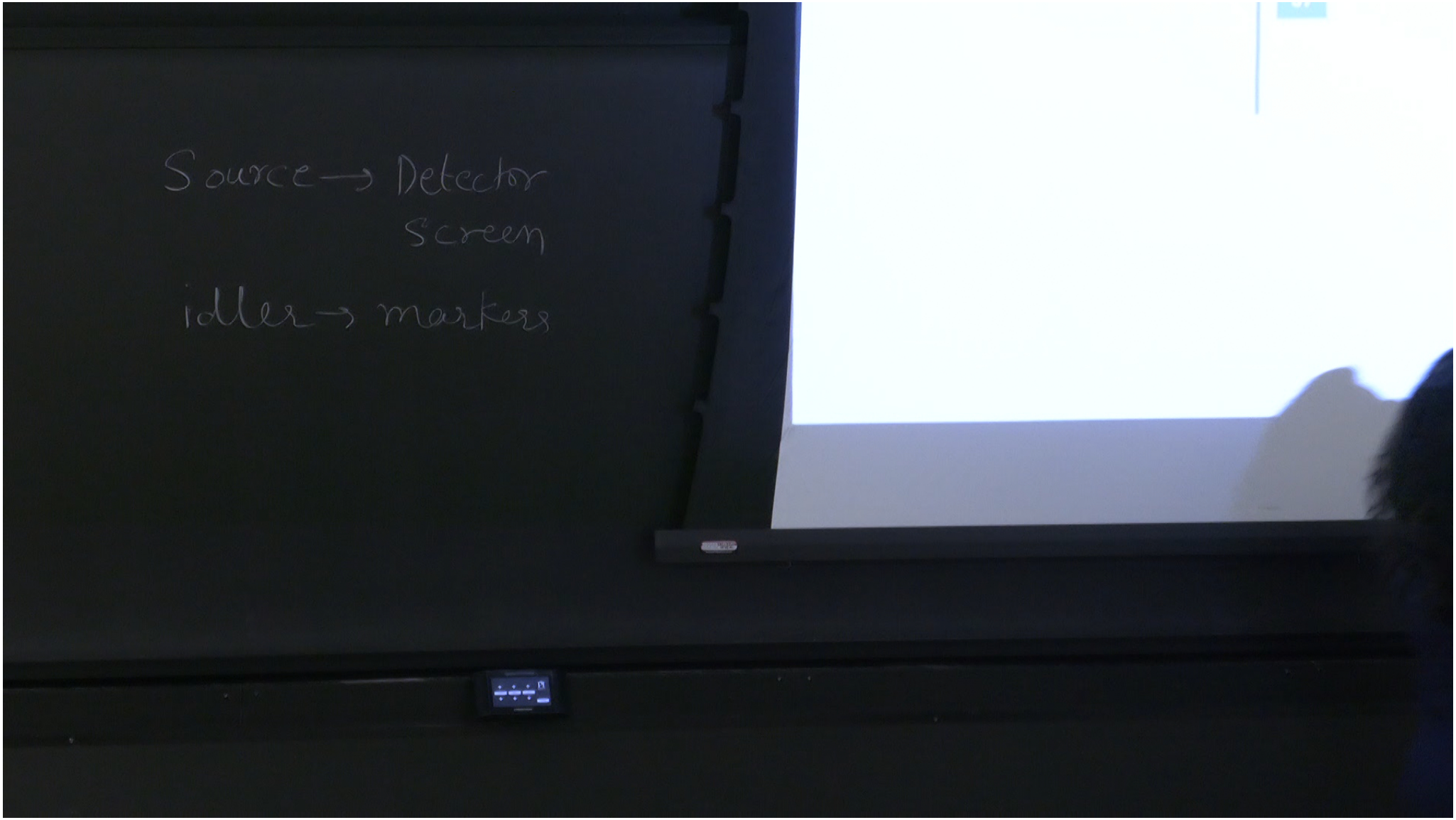
The Copenhagen interpretation

Born, Heisenberg, Bohr



It requires a process called **wave function collapse**
for which there is no known physical explanation

Image Source : www.afriedman.org


Source → Detector
screen
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