

Title: Quantum Theory Lecture - 090623

Speakers: Bindiya Arora, Dan Wohns

Collection: Quantum Theory 2023/24

Date: September 06, 2023 - 10:45 AM

URL: <https://pirsa.org/23090039>



Quantum Theory



Dr Bindiya Arora

PSI Fellow

Perimeter Institute for Theoretical Physics, Canada



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

2

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

4 Fourth Lecture

Working With Ensembles

Density Matrix
Measurement & Decoherence
Composite Systems

6 Sixth Lecture

From Particles to Fields

Field (Scalar)
Bunch of Oscillators
Propagating Disturbances

3 Third Lecture

Time Dependent Potentials

Interaction Picture
Fermi Golden Rule
Rabi Oscillations

5 Fifth Lecture

Which Way? Why This Way?

Path Integral Formalism
Classical vs Quantum
How to Interpret

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

6

Ask Station



slido



Google Forms



Observations



Individual Particles

Whole Particle

All Same

Particles hit screen at **Random Positions** = **No pattern in trajectory**
However we find pattern in the **Probabilities**

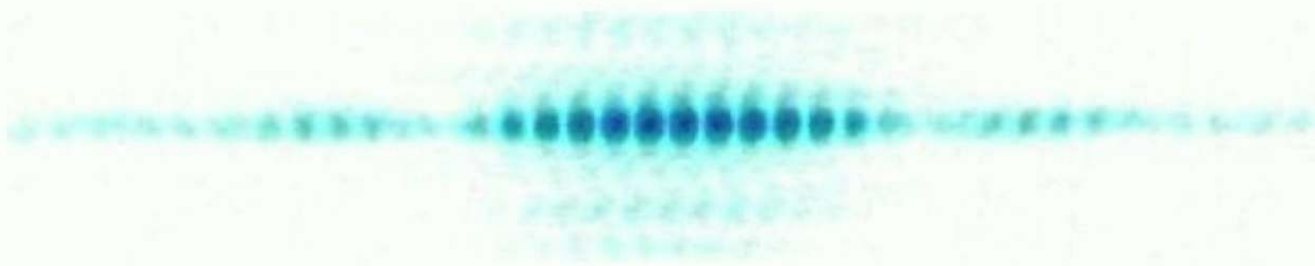


“the double-slit experiment has in it the heart of quantum mechanics. In reality, it contains the only mystery”

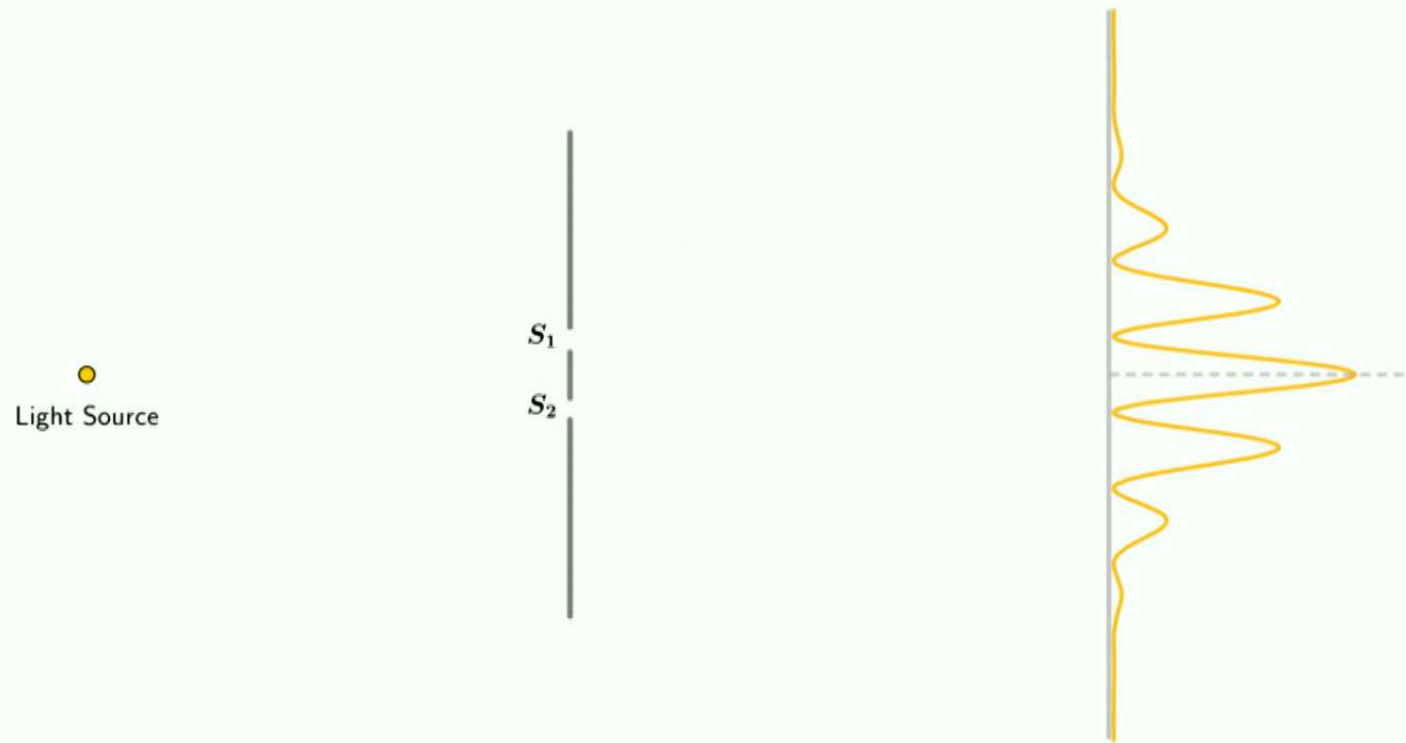
Richard P. Feynman

Double-slit experiment

First performed by Thomas Young in 1801

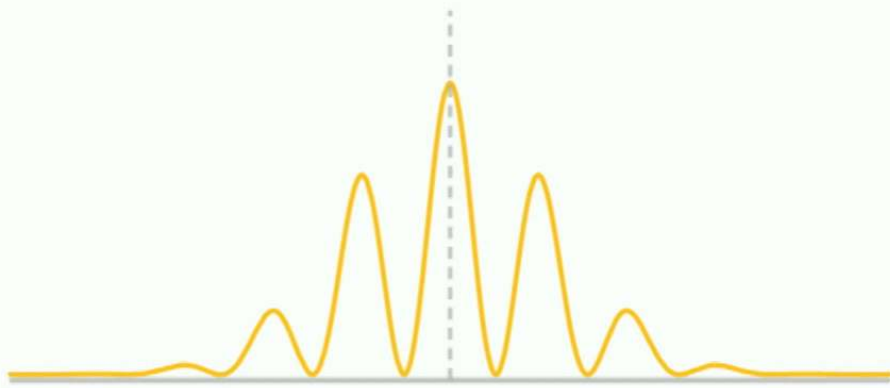


A Quick Recap

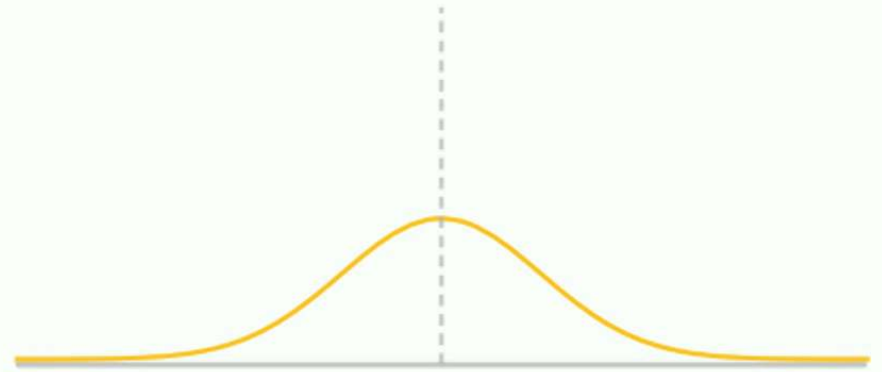


Hillmer R, Kwiat P. A do-it-yourself quantum eraser. *Sci Am.* 2007 May;296(5):90-5.

Doi: [10.1038/scientificamerican0507-90](https://doi.org/10.1038/scientificamerican0507-90). PMID: 17500419.



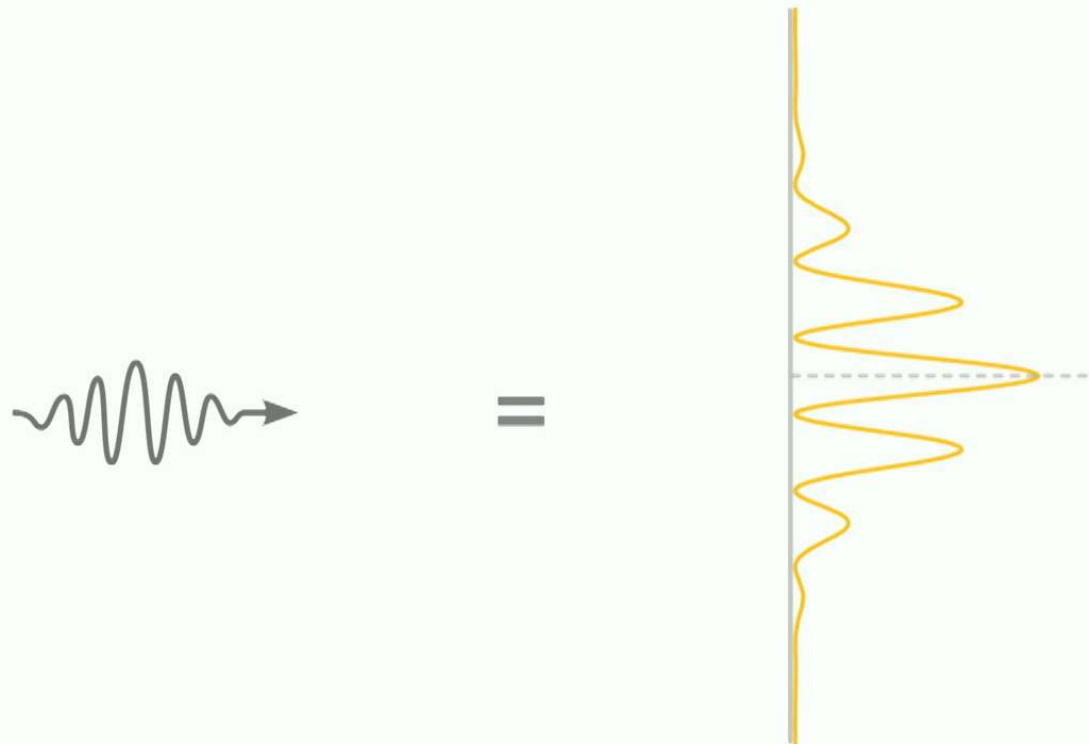
Double-Slit



Single-Slit

Possible Interpretations

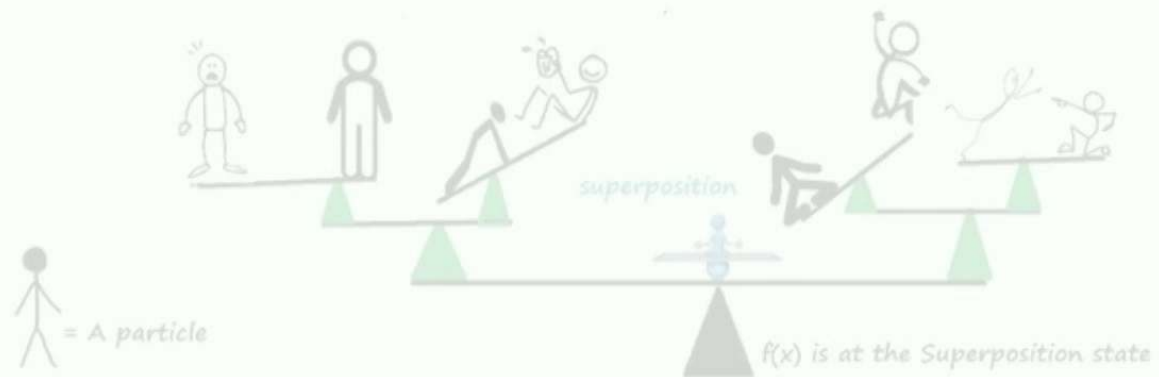
- Each particle **passes through one of the two slits** and interacts with other particles
- Each particle **interacts with both slits**



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

Superposition

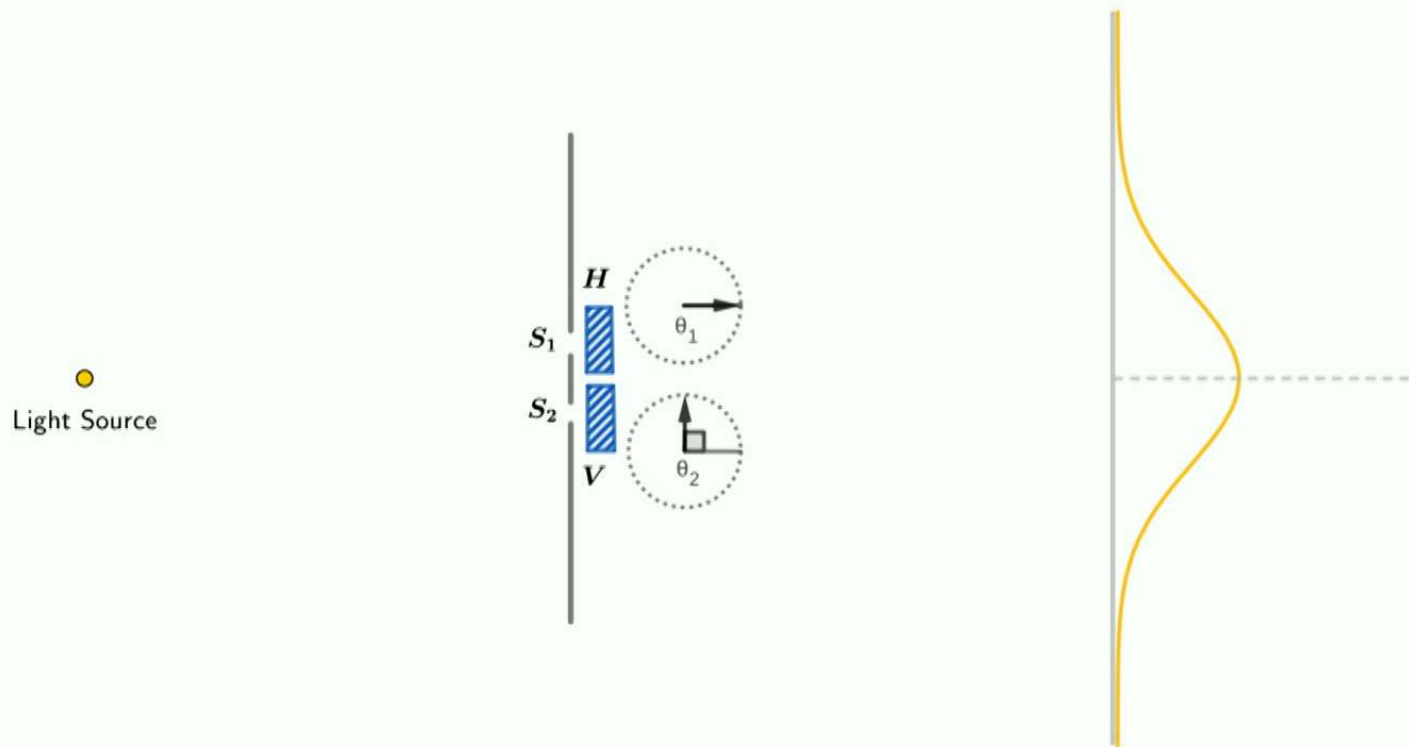
$$|\psi\rangle = |\psi\rangle_{s_1} + |\psi\rangle_{s_2}$$



Does the particle pass through both of the slits ?

The Which Way Information

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

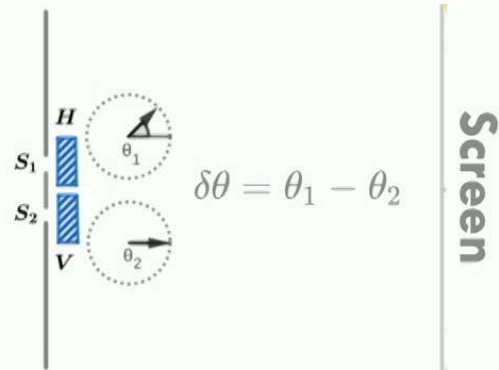


Marking States

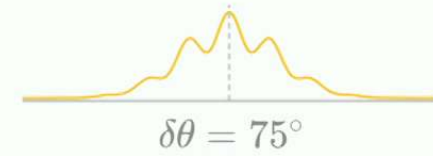
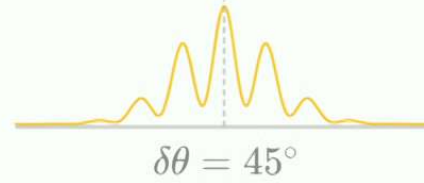
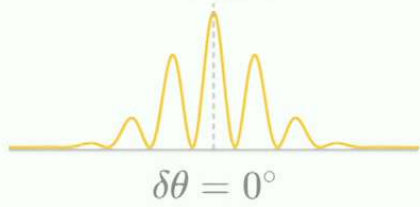
$$|\psi\rangle = \frac{|\psi\rangle_{s_1} |H\rangle + |\psi\rangle_{s_2} |V\rangle}{\sqrt{2}}$$

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

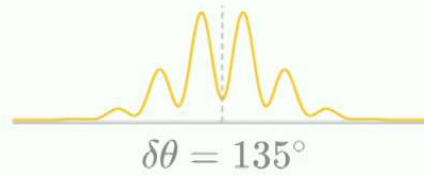
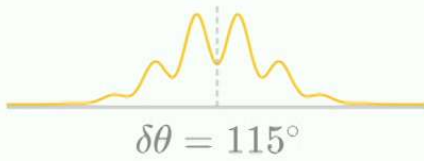
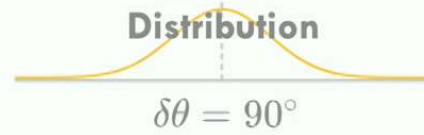
Light Source



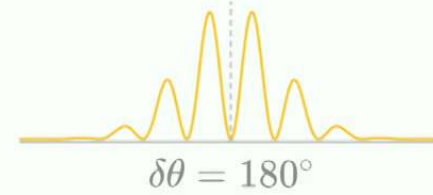
Fringes



Normal Distribution

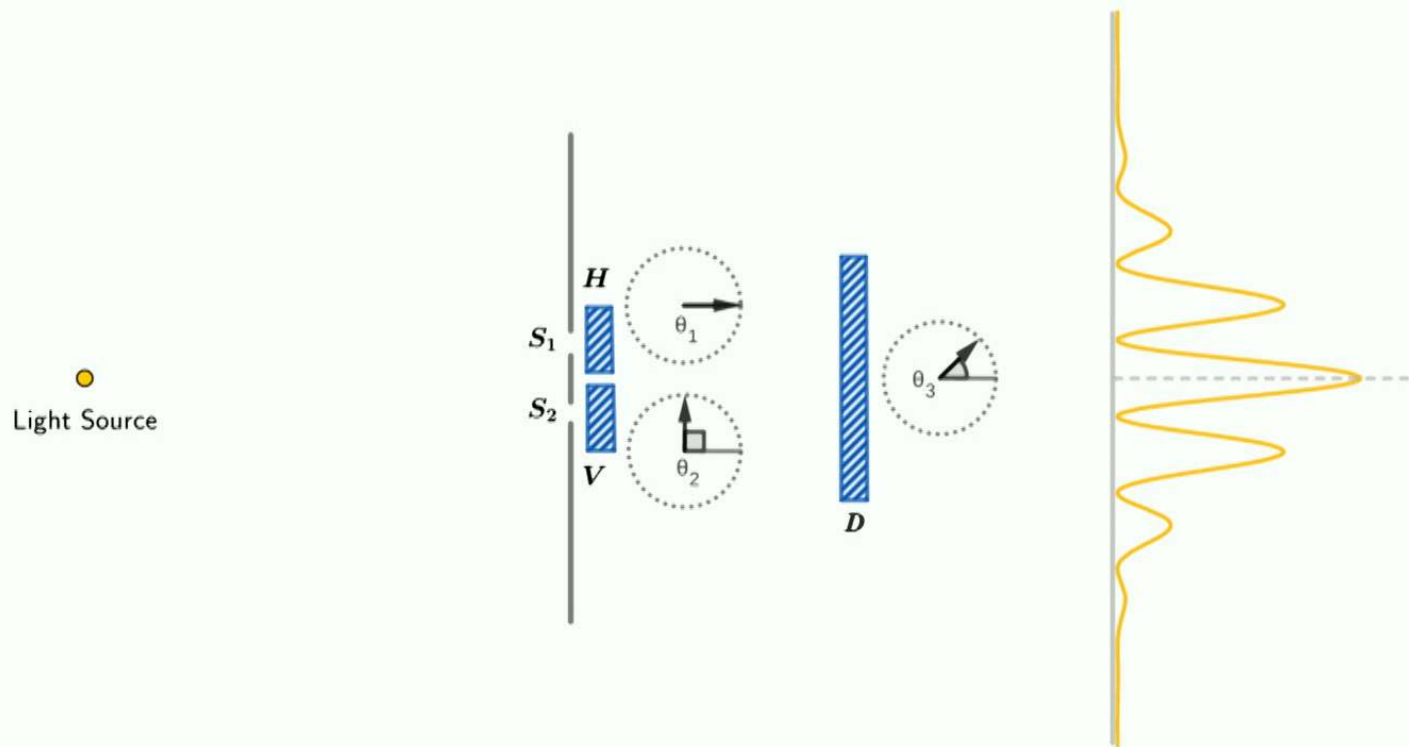


Anti-Fringes



Quantum Erasers

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



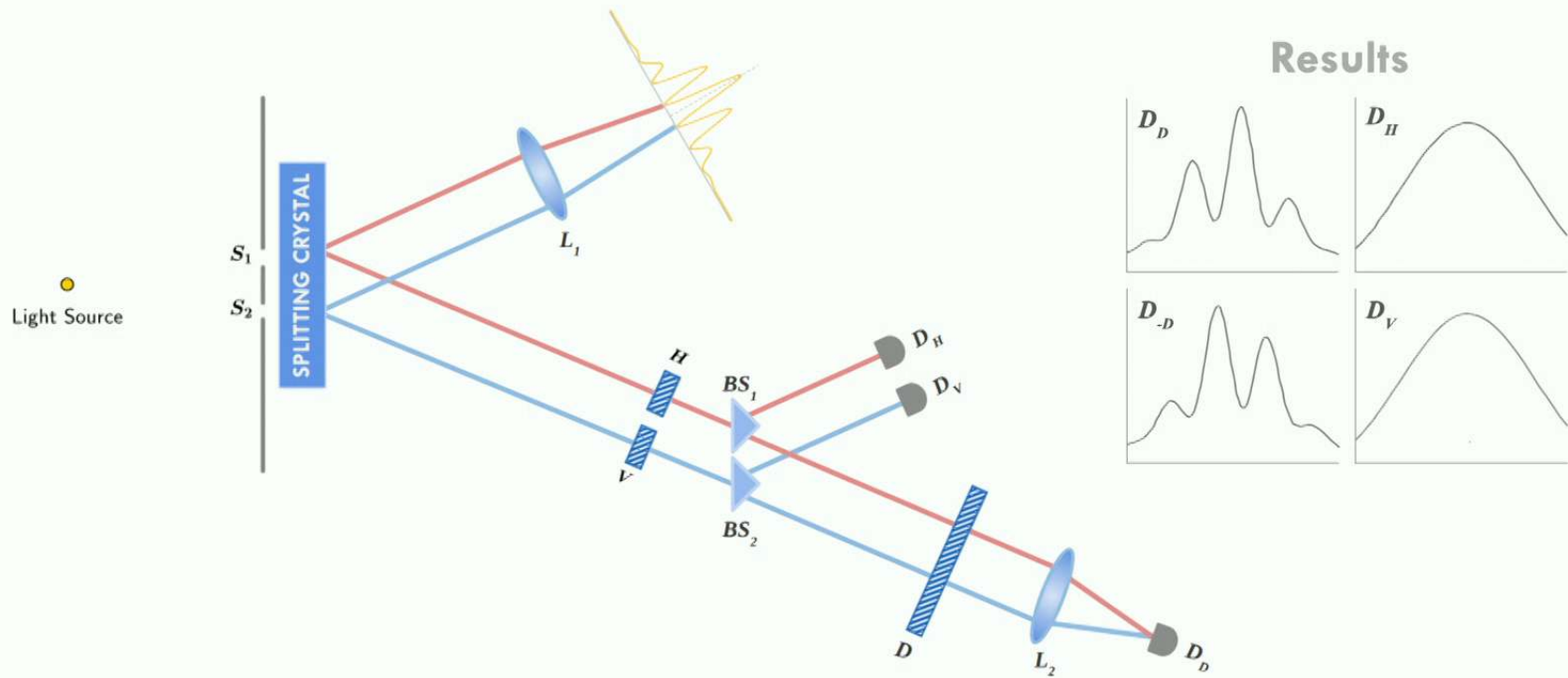
Eraser

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

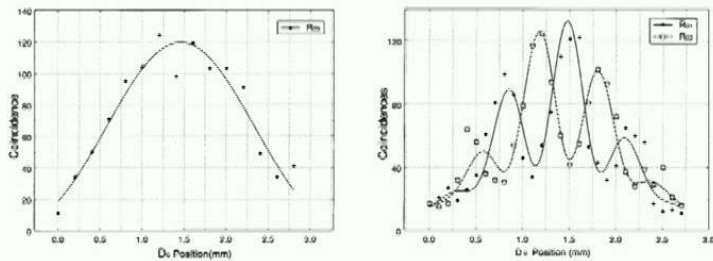
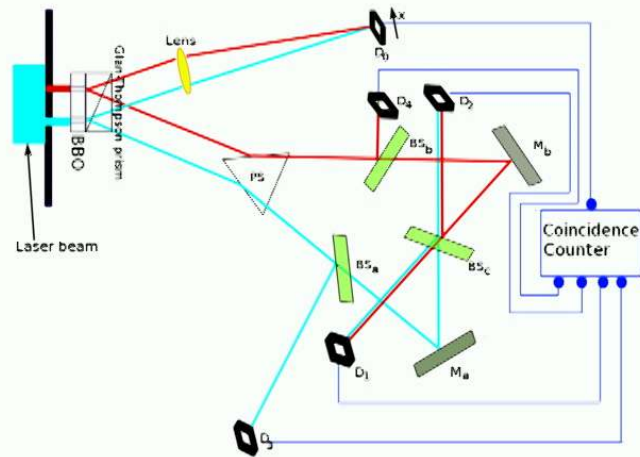
where $|D\rangle = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 \\ 1 \end{bmatrix}$

Delayed Choice

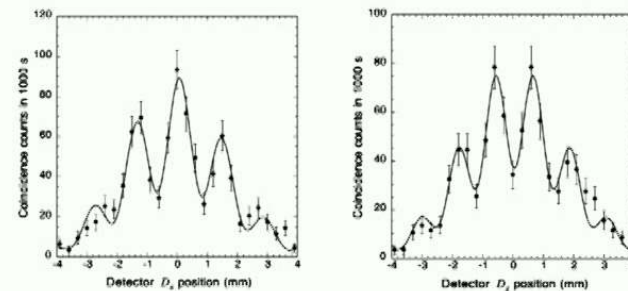
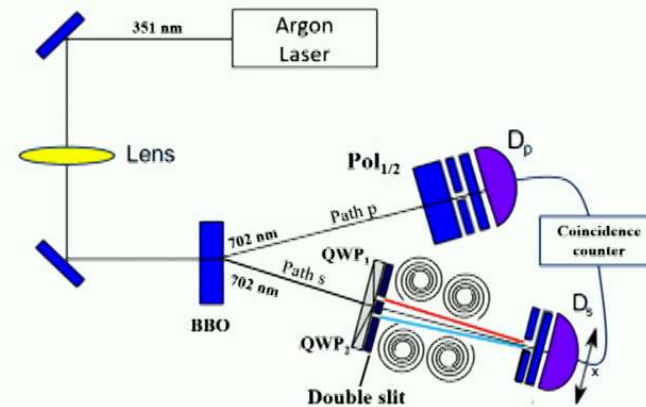
Even if we want our eraser to act after photon hits the screen, still pattern reappears



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

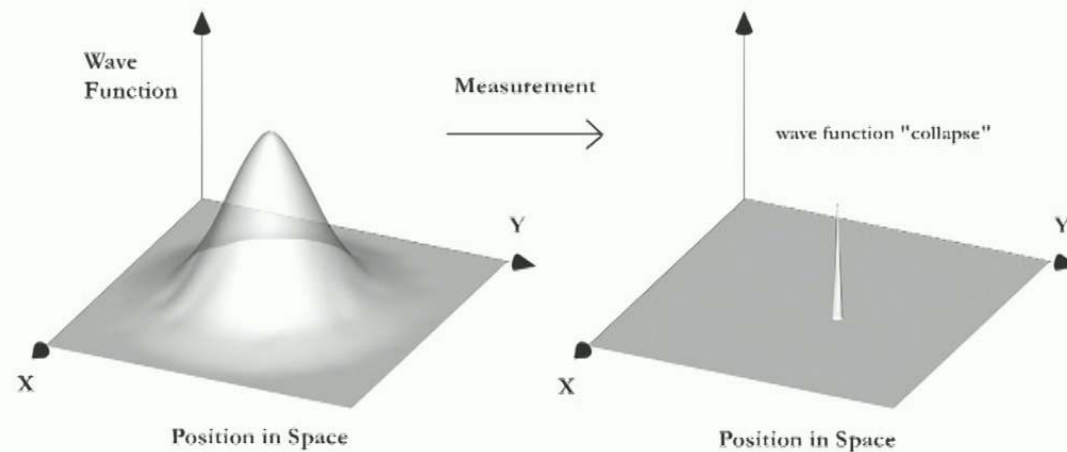
- The particle was there
- The uncertainty reflects our ignorance, some additional information (**hidden variable**) is needed

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

idler → markers