# Classical Analogues to Quantum Coherence

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## Summary

- Classical wave interferometry can behave as an analogue to properties of quantum Hong-Ou-Mandel interference
- Using a continuous wave laser, we can examine the effect of polarization on coherence
- Mixed initial polarizations can function as a partial analogue to interference of polarization-entangled photons

## Quantum Hong-Ou-Mandel Interference

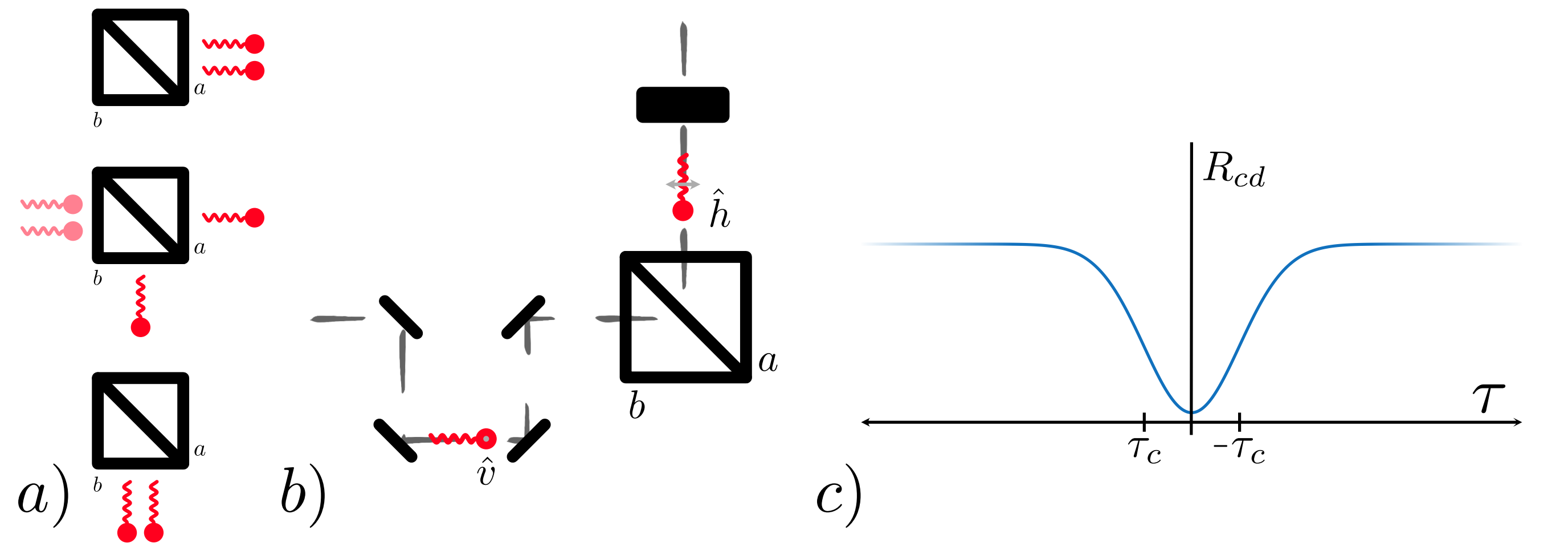


**Fig. 1:** Diagrams of Hong-Ou-Mandel interference showing a) the possible outcomes of photons entering a beamsplitter, b) affecting coherence with time delays and changes in polarization, and c) the Hong-Ou-Mandel dip produced by a variable time delay

- Coherent photons exiting a beamsplitter will only exit through the same port due to Hong-Ou-Mandel interference [1]
  - Coherence depends on photons being indistinguishable, and adjusting the degree of coherence results in a characteristic Hong-Ou-Mandel "dip," shown in Fig. 1c
- A classical analogue to this can be created using a Mach-Zehnder interferometer with a pulsed laser as the source
  - Pulsed shaped waves interfering will create a "dip" envelope shaped like HOM interference, but with interference between waves also present
  - A CW laser yields results equivalent to a pulsed source with no time delay

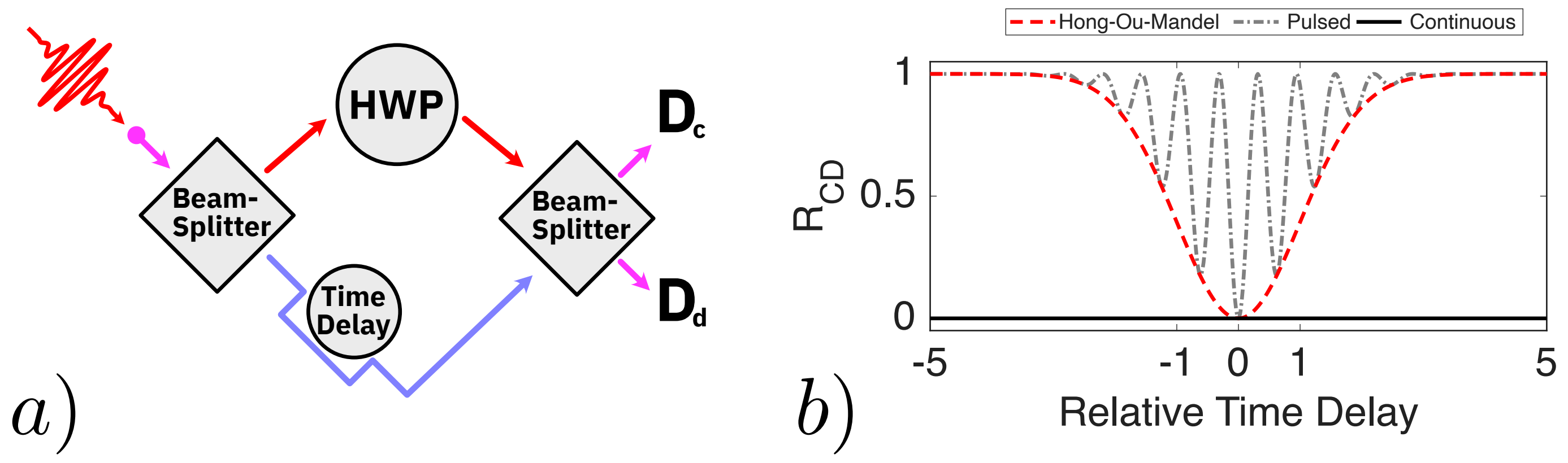


**Fig. 2:** a) Diagram of a classical analogue to quantum interference. A laser pulse is split by a beam-splitter, and the relative phase and polarization of each beam are adjusted before being recombined by a second beam-splitter, and the rate of coincident detections between two detectors is recorded. b) Plot of the results of quantum Hong-Ou-Mandel interference and classical interference with a pulsed or continuous wave source.

## Interference of Polarization-Entangled Photons

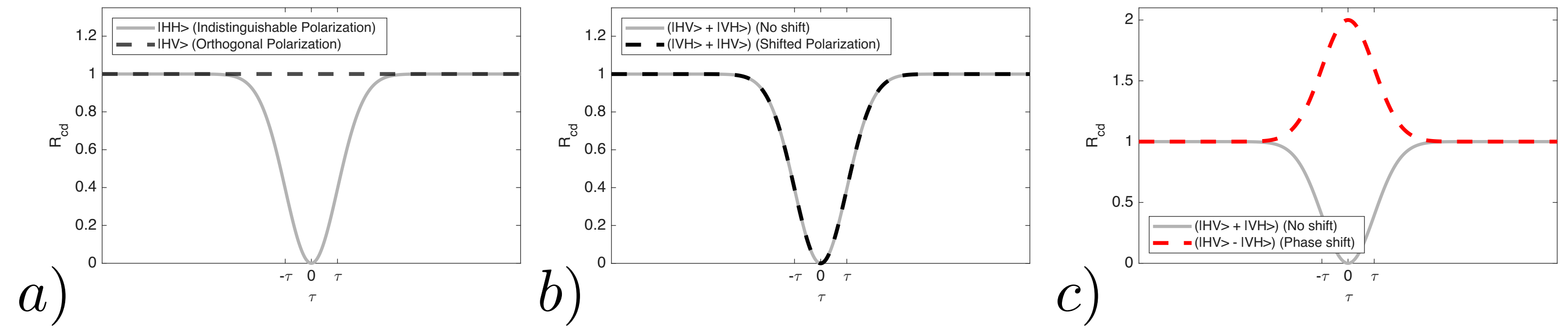
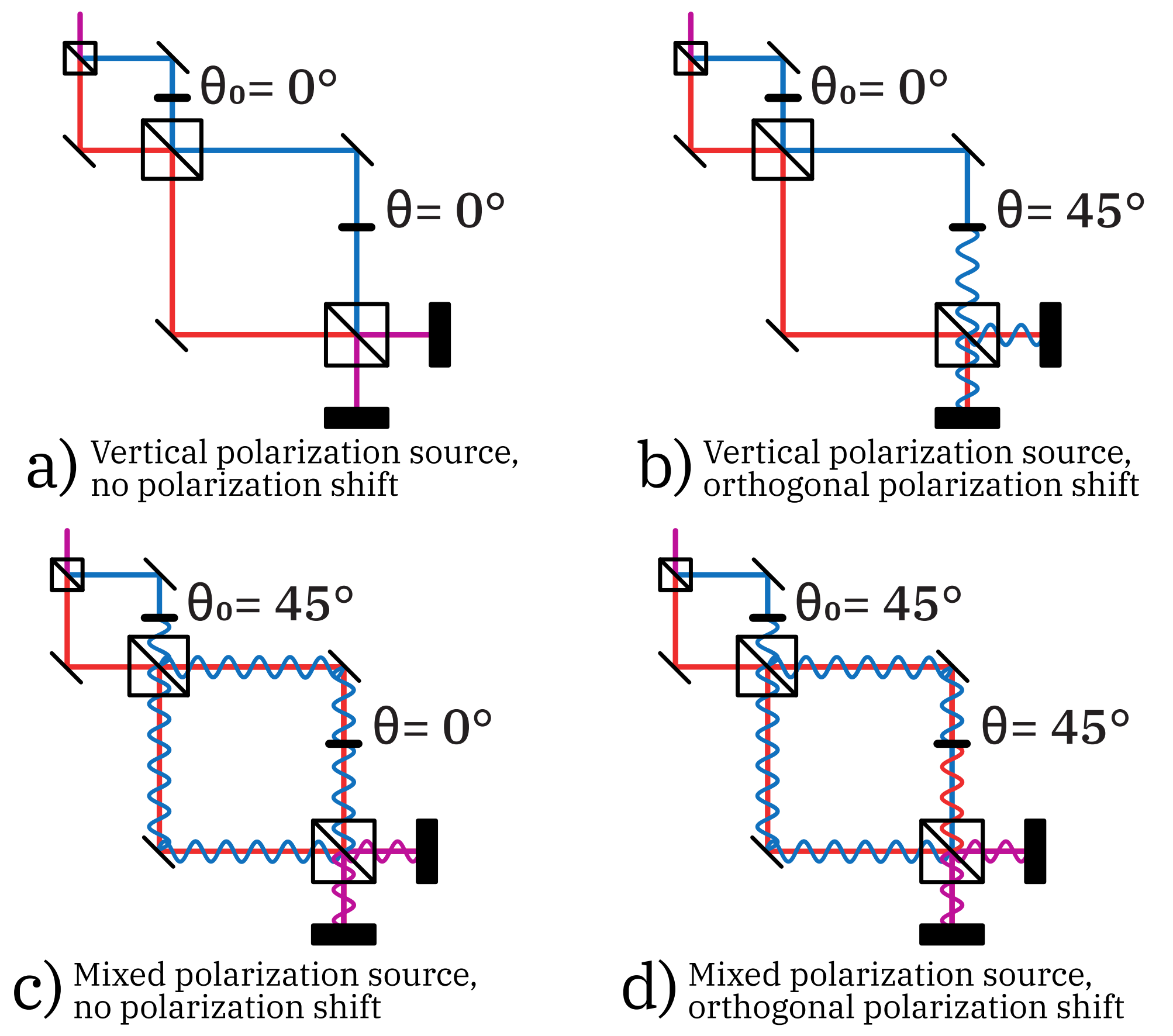


**Fig. 3:** HOM dips from a) non-entangled photons, b) entangled photons, and c) photons whose entangled photons are phase-shifted

- The photons entering the interferometer could have the same (|HH>), orthogonal (|HV>), or entangled polarizations
  - Entangled polarizations are in a superposition (|HV> + |VH>), where it's known that there is one horizontally and one vertically polarized photon, but not which individual photon is which
- Changing the polarization of a photon before the interferometer doesn't change the net superposition of each path, so interference is preserved [1]
- This is analogous to light in a mixed polarization state entering a classical interferometer, shown in Fig. 4
  - Light will be both horizontally and vertically polarized, so changing which is which along one path will not affect interference
  - This analogue fails when considering the quantum phase between entangled states, which can produce a Hong-Ou-Mandel peak (Fig. 3c)



a) Vertical polarization source, no polarization shift
b) Vertical polarization source, orthogonal polarization shift
c) Mixed polarization source, no polarization shift
d) Mixed polarization source, orthogonal polarization shift

**Fig. 4:** Diagram of each case of the entanglement analogue

## Experimental Design & Results

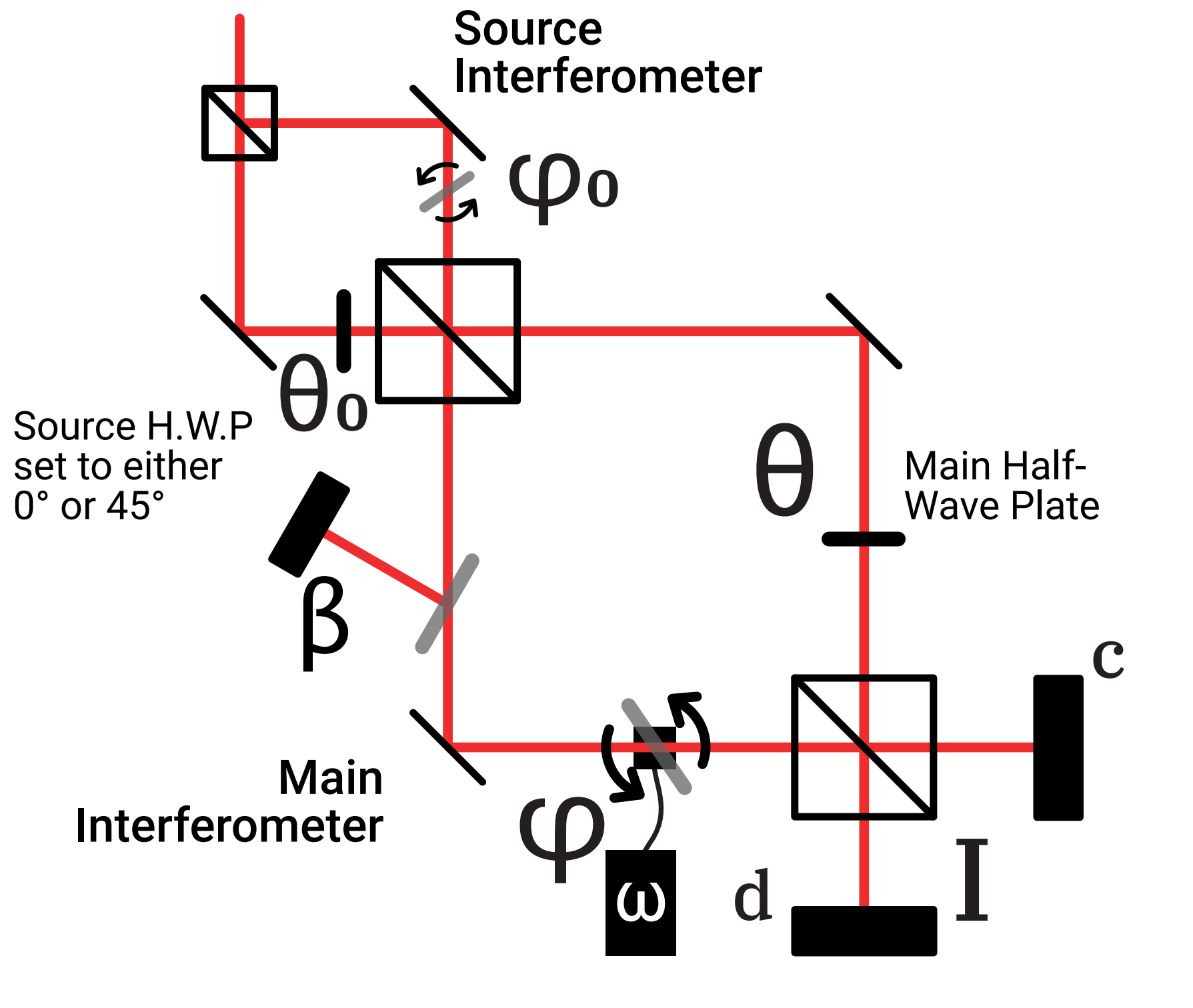


**Fig. 5:** Diagram of the complete experimental setup

- These experimental predictions were tested using a double Mach-Zehnder interferometer, shown in Fig. 5
  - Made of a "source" interferometer that affects the light entering the "main" interferometer
- In one test (Fig. 6), the effect of polarization on coherence was tested by varying the angle θ of the main half-wave plate
- To test the entanglement analogue (Fig. 7), we set the angle of the initial half-wave plate to either 0° (no change in polarization) or 45° (producing mixed polarization), and measured how much adjusting the main half-wave plate to produce orthogonal light affected coherence

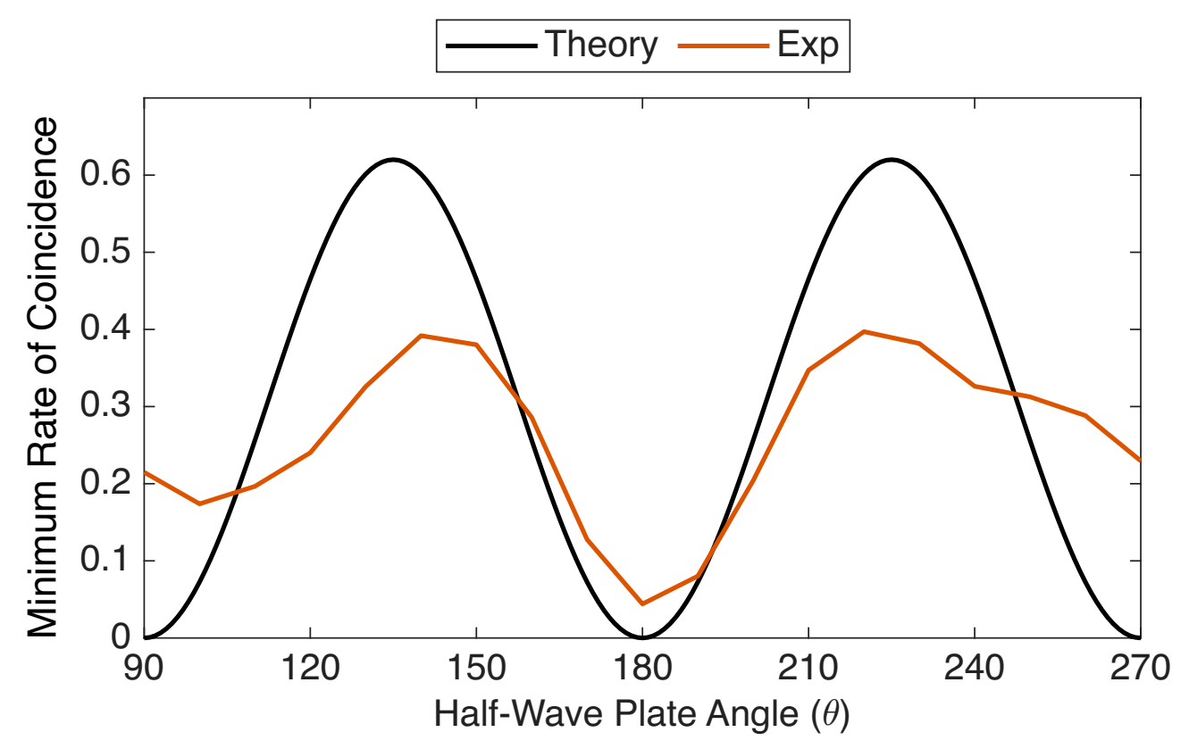


**Fig. 6:** Experimental results from a single input with varying polarization, with the theoretical prediction overlaid.

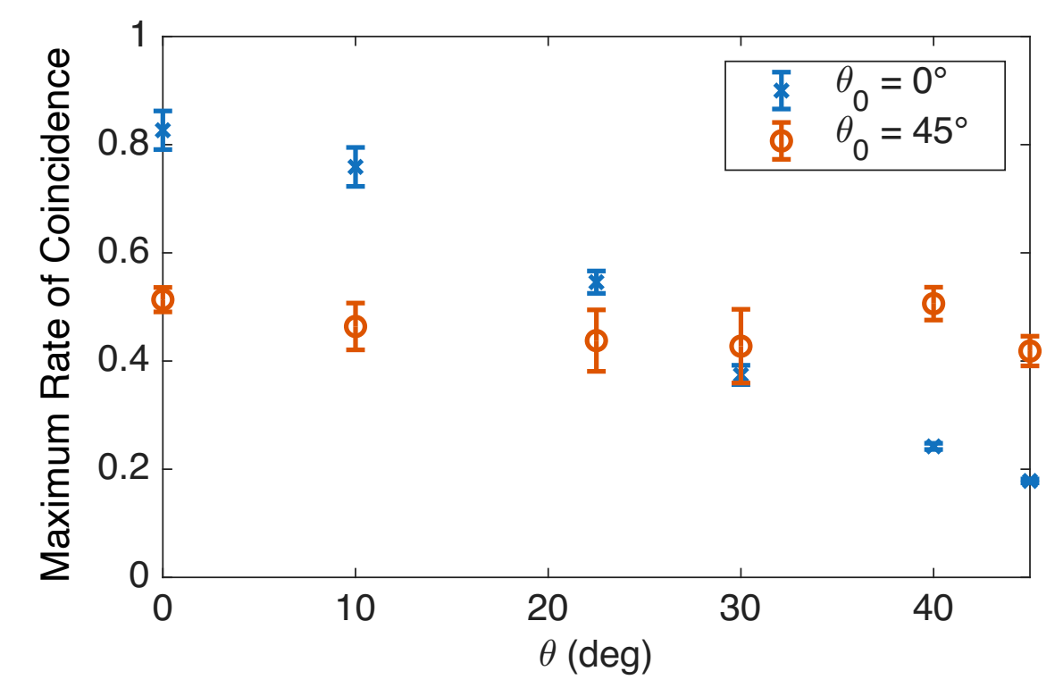


**Fig. 7:** Interference produced by a multi-source interferometer as the shift in polarization of the main interferometer changes, with either vertical or mixed initial polarization.

## Acknowledgments

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## References

[1] Madelyn E. Noll. Polarization-Dependent Behavior of Entangled Two-Photon States. Senior IS, College of Wooster, March 2025.

## Future Work

- Experimentally, the current setup uses a continuous wave source and photo-detectors. Changing to a pulsed source and single photon detectors will produce a closer analogue
- Theoretically model quantum equivalents to several parts of the classical analogue