

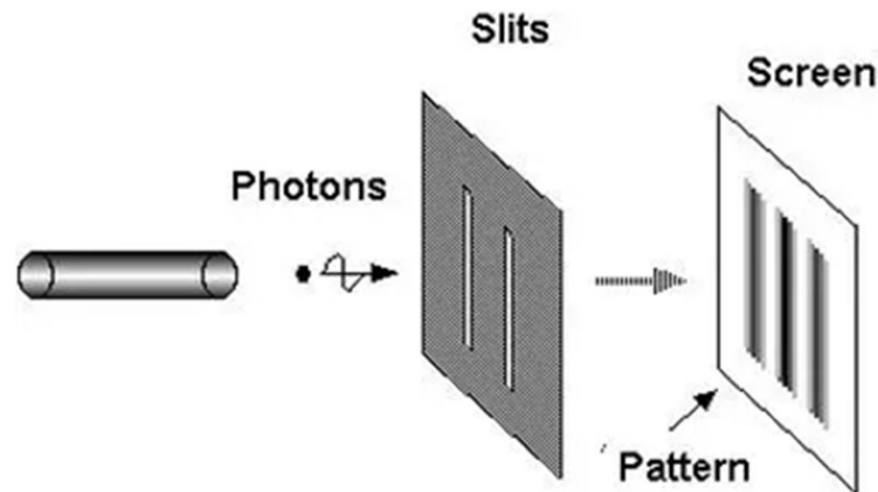
# Delayed “Choice” Quantum Eraser

*Yoon-Ho Kim, Rong Yu, Sergei P. Kulik, Yanhua Shih, and Marlan O. Scully*

*Phys. Rev. Lett. 84, 1 – Published 3 January 2000*

Team 8

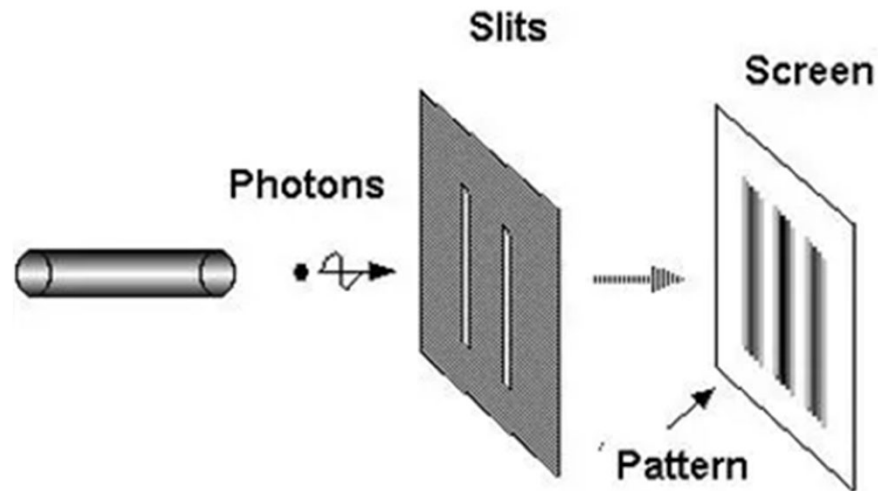
# Discovery of Double-Slit Interference



source: <https://www.testandmeasurementtips.com/thomas-young-and-the-double-slit-experiment/>

- An interference pattern arises when photons pass through two parallel slits.
- Originally carried out by Thomas Young in 1801.
- Any attempt to figure out which slit the photon went through destroys the interference pattern.
  - Example: By having a detector either before or after the slits.

# "Which Way" Experiment to Determine Photon Path

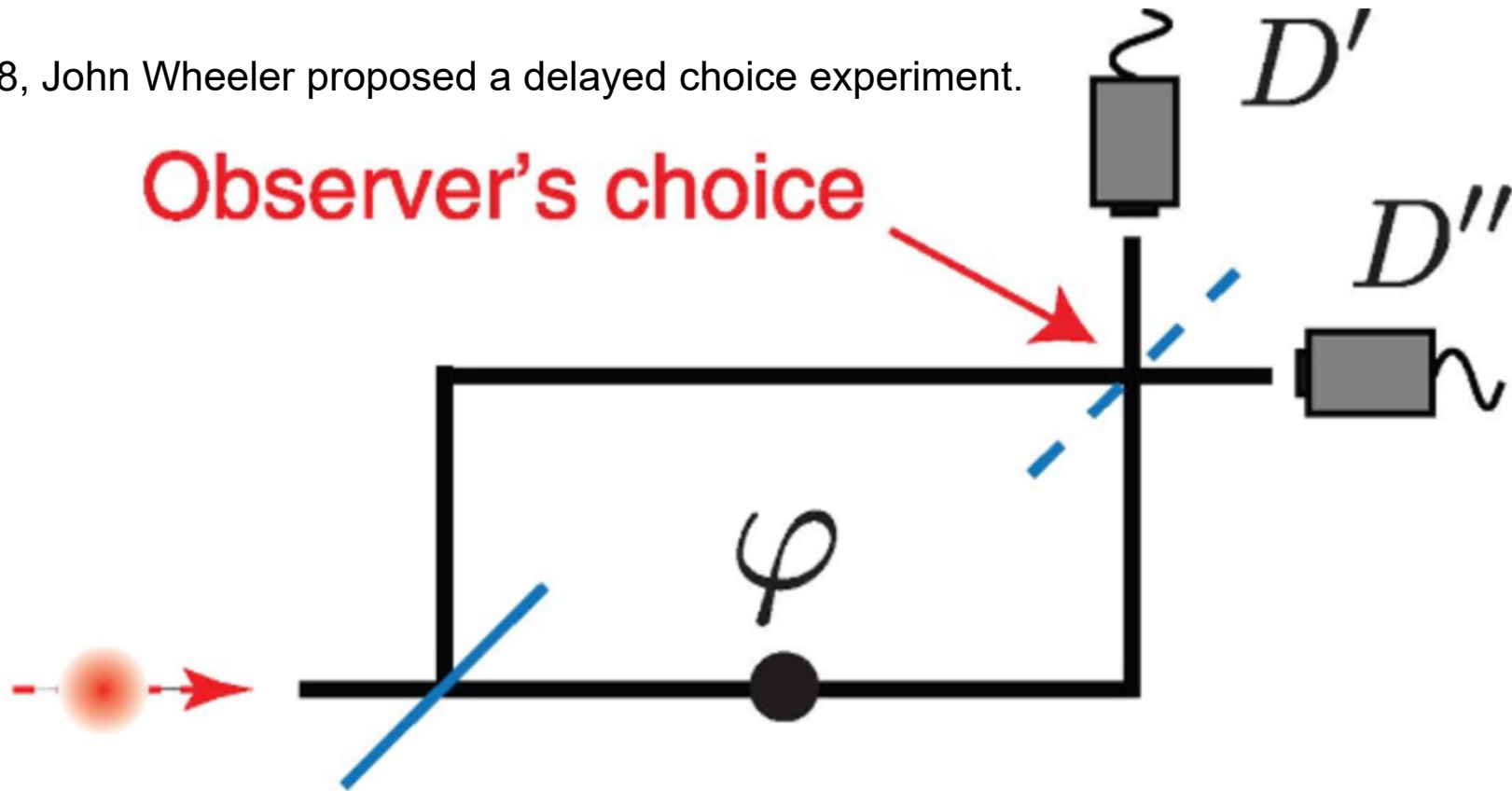


source: <https://www.testandmeasurementtips.com/thomas-young-and-the-double-slit-experiment/>

- Coherence of the waves allows for the interference pattern to be observed.
- “**which way**” experiment is a modification of the double-slit experiment used to determine which slit the photon passes through.
- A test that is performed after the photons have passed through the slits is known as a **delayed choice** experiment.

# Wheeler's Proposal to Determine "Which Way"

- In 1978, John Wheeler proposed a delayed choice experiment.

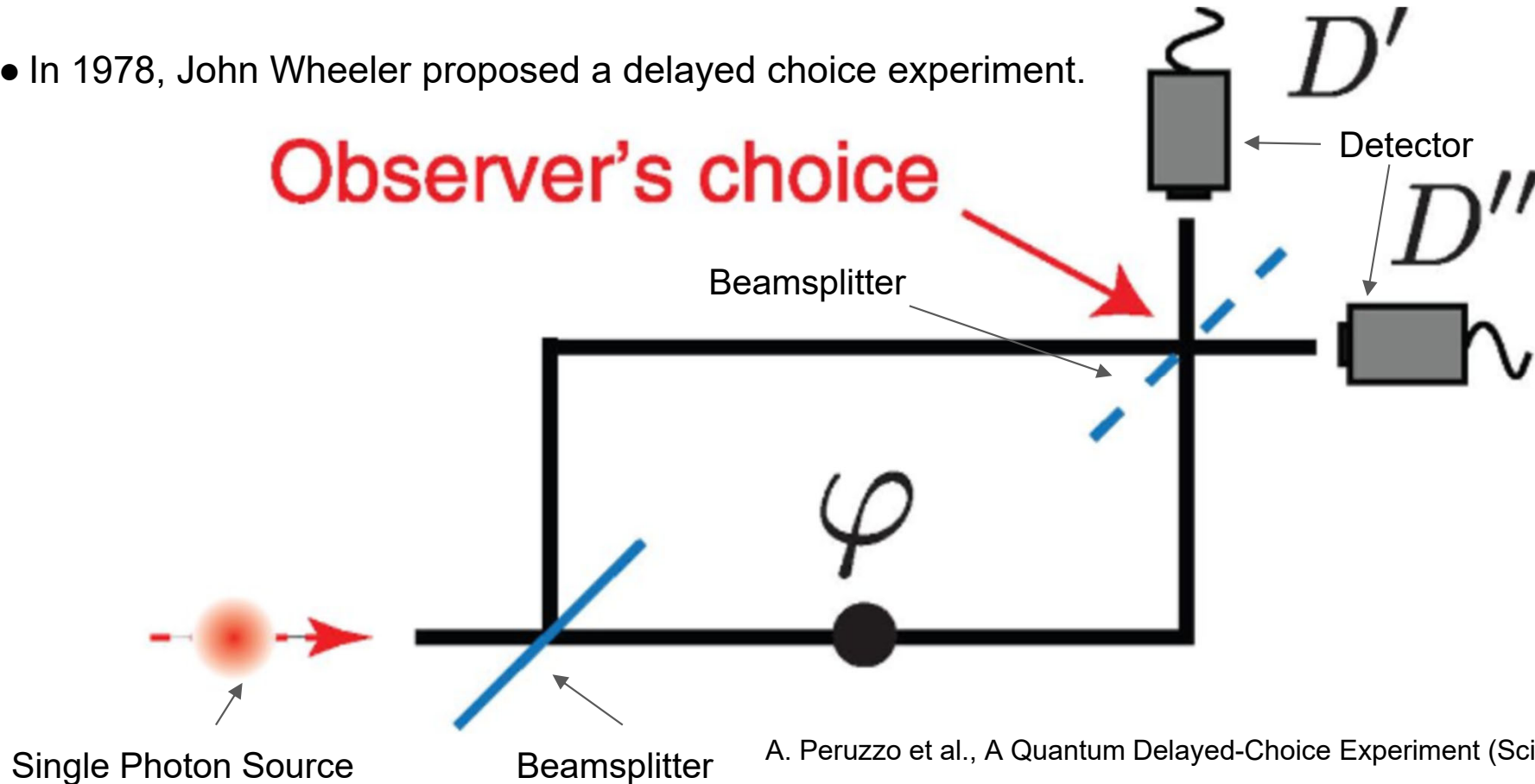


A. Peruzzo et al., A Quantum Delayed-Choice Experiment (Science, 2012).

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Observer's choice

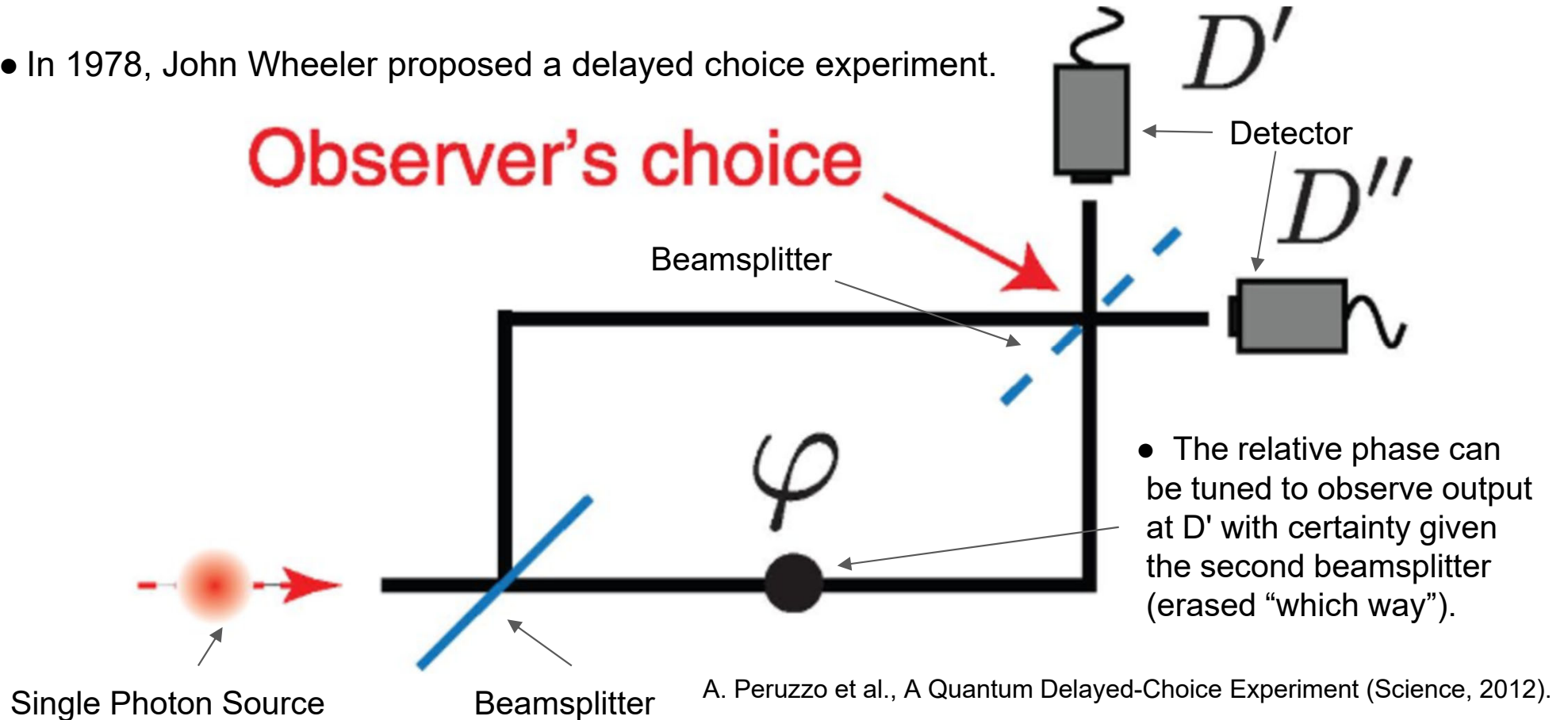


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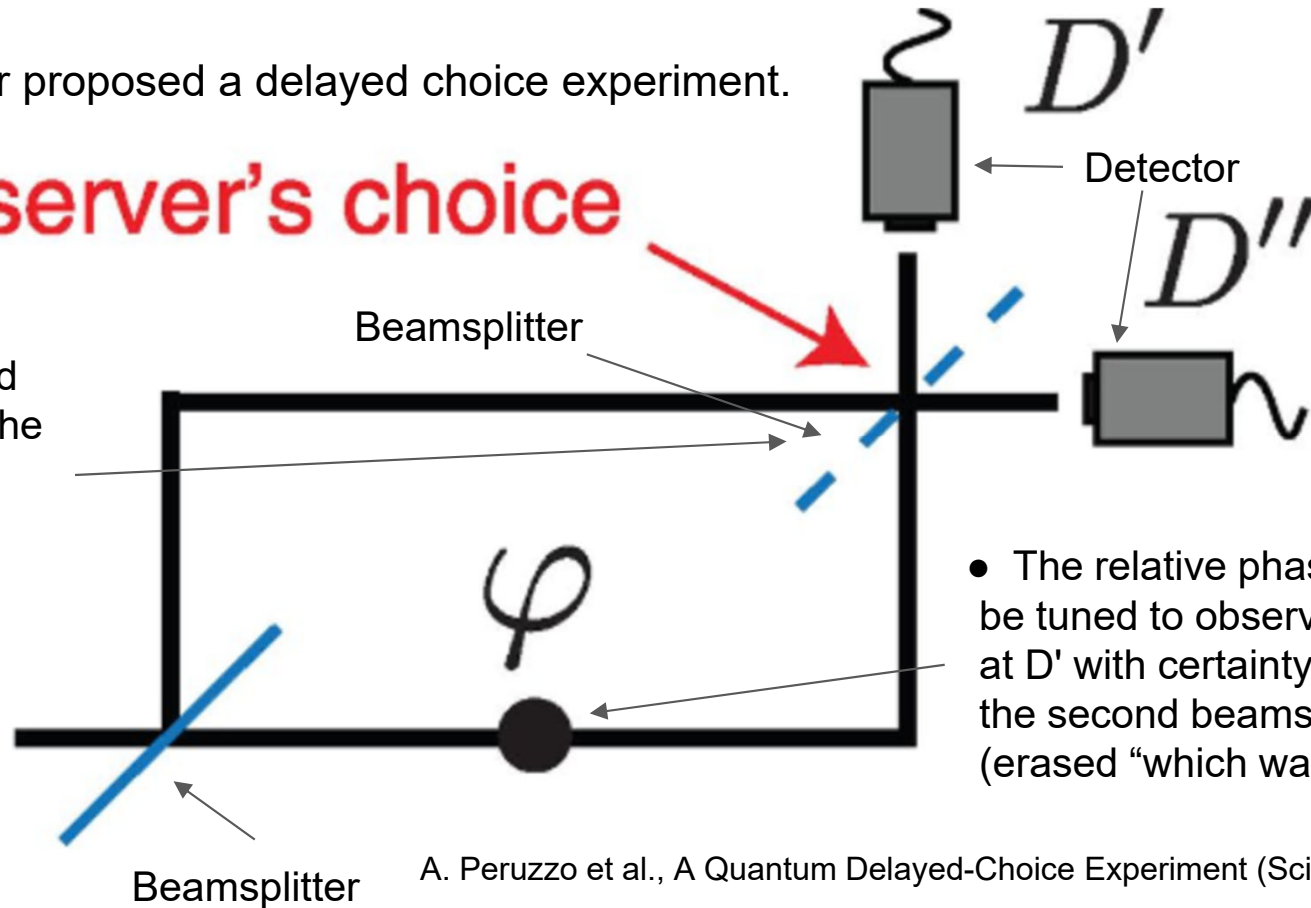
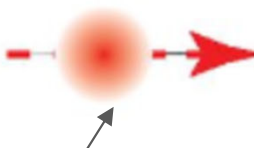
# Wheeler's Proposal to Determine "Which Way"

- In 1978, John Wheeler proposed a delayed choice experiment.

**Observer's choice**

- The presence (or absence) of a second beamsplitter allows the observer to choose whether to measure "which way" or interference.

Single Photon Source



- The relative phase can be tuned to observe output at  $D'$  with certainty given the second beamsplitter (erased "which way").

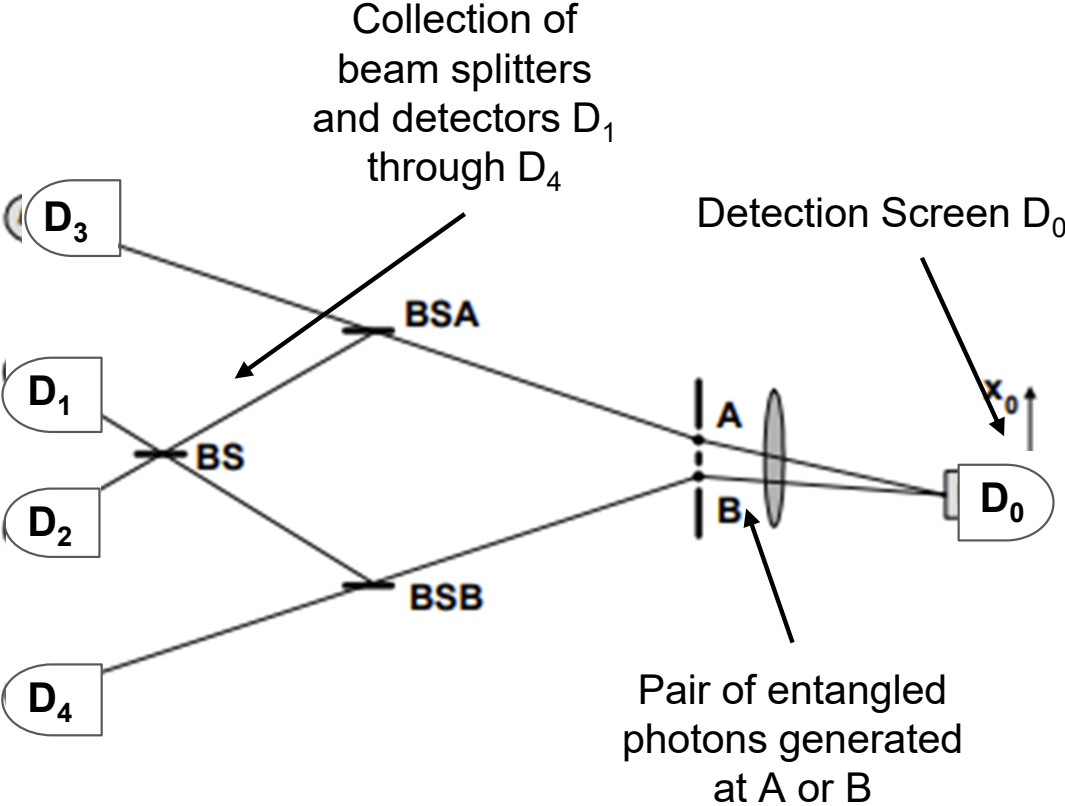
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# Wheeler's Delayed "Choice" Quantum Eraser

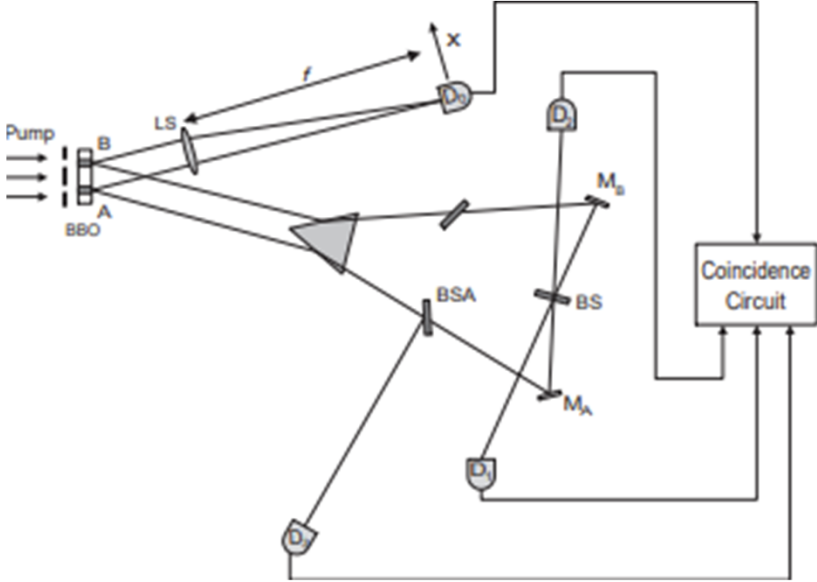
- Having both beam splitters constitutes a "quantum eraser".
- Having single beam splitter constitutes a "which way".
- Ensure a spacelike separation between the two beam splitters.
- Particle cannot know in advance which experiment is performed.
- Allows us to combine the quantum eraser with a delayed choice.



# Experimental Setup

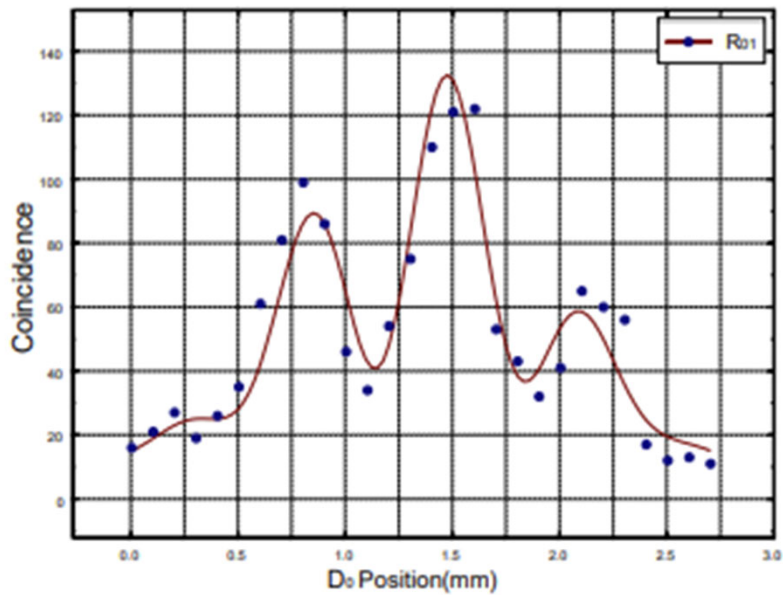


Full apparatus used in the experiment

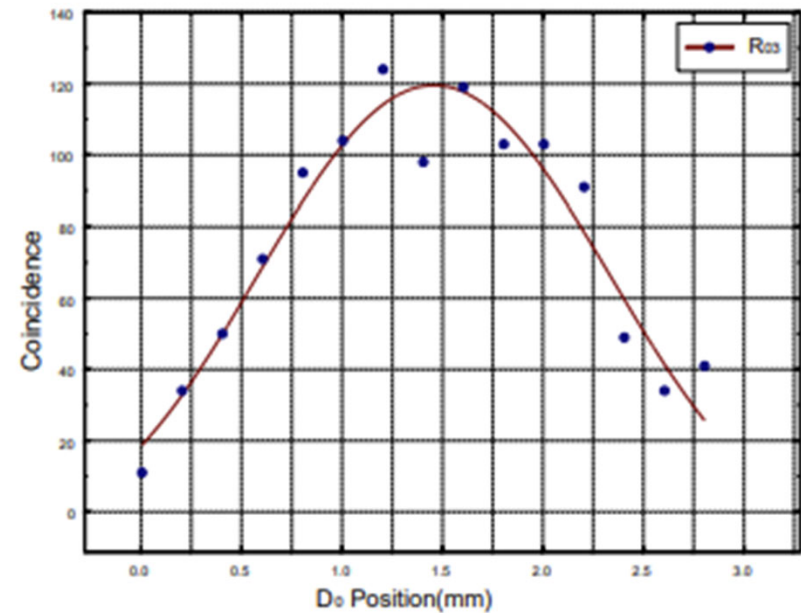


# Effect of Path Information on Detector Screen Distribution

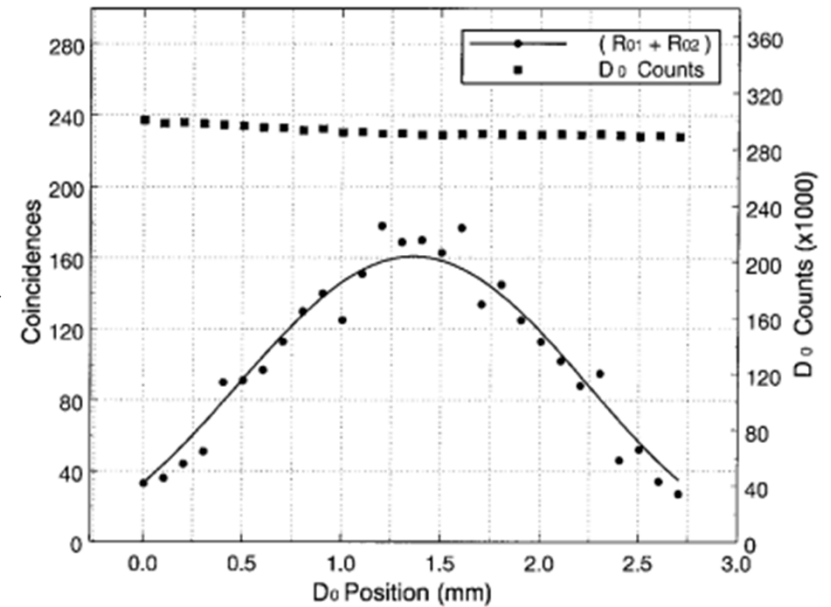
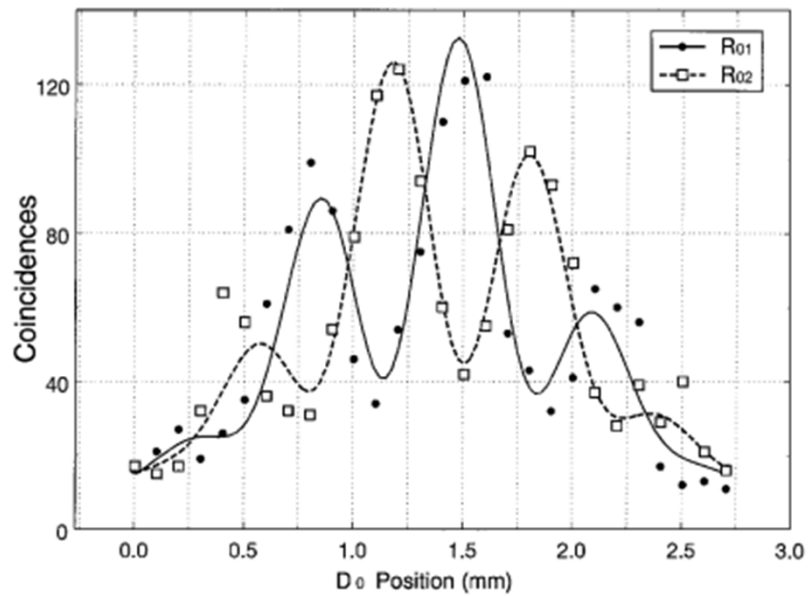
Joint detection rate  $R_{01}$  between detectors  $D_0$  and  $D_1$



Joint detection rate  $R_{03}$  between detectors  $D_0$  and  $D_3$



# Interference Disappears when Considered Collectively



The sum of the interference patterns produces a distribution similar to that of the photons whose which-path information was known

# Conclusion

The study concluded that:

- Particlelike and wavelike behaviors of a photon can be determined via quantum entanglement.
- The which-path or both-path information of a quantum can be erased or marked by its entangled twin even after the registration of the quantum itself.

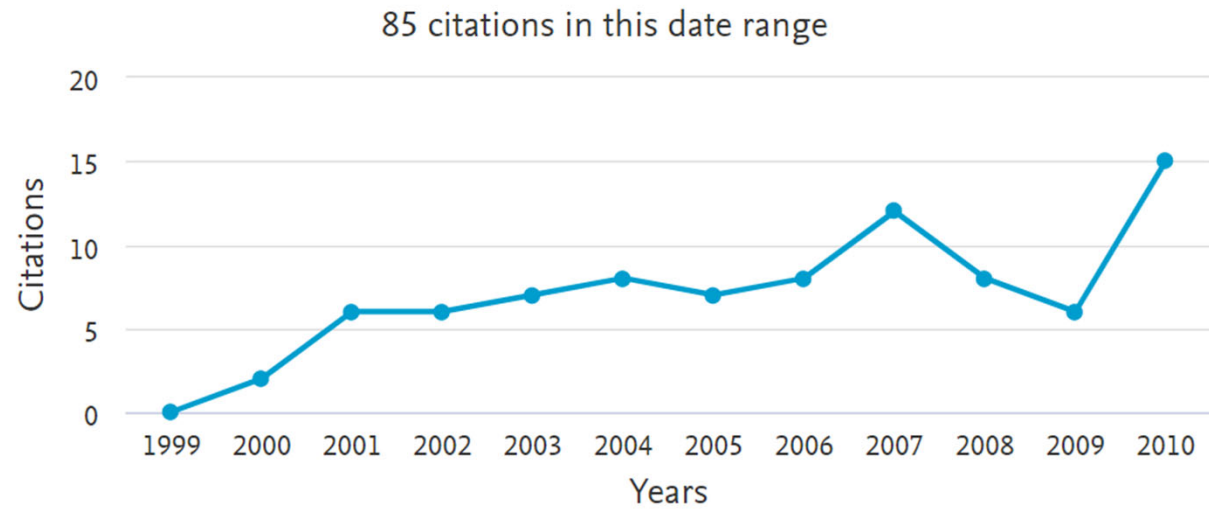
# Critique

- Paper lacks information about experimental errors and uncertainties.
- For example, resolution of the step motor (determines photon location along x axis) is not provided.

# Citation evaluation

Total citations = 336 (scopus)

Source: scopus

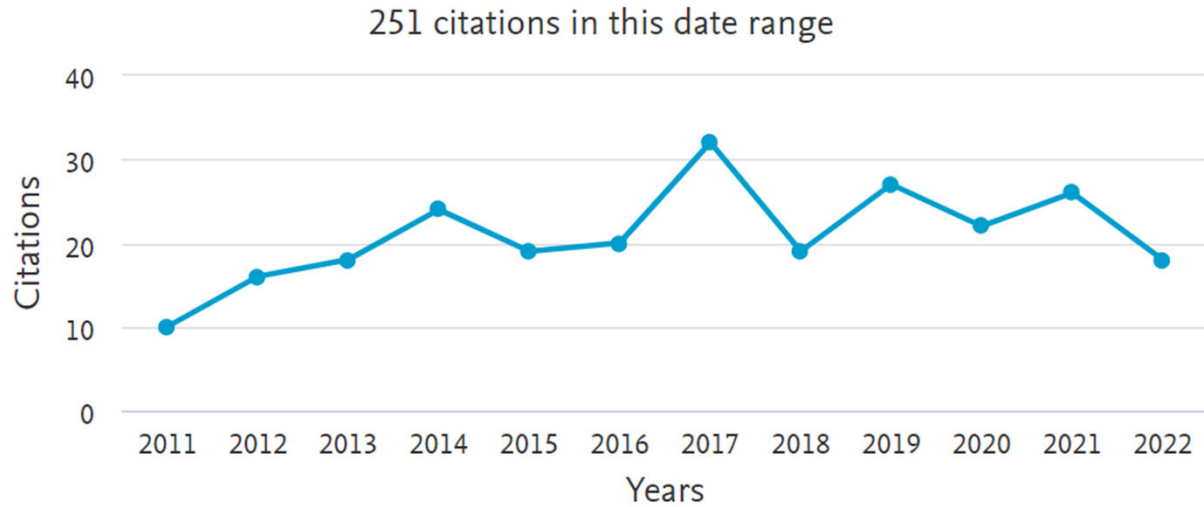
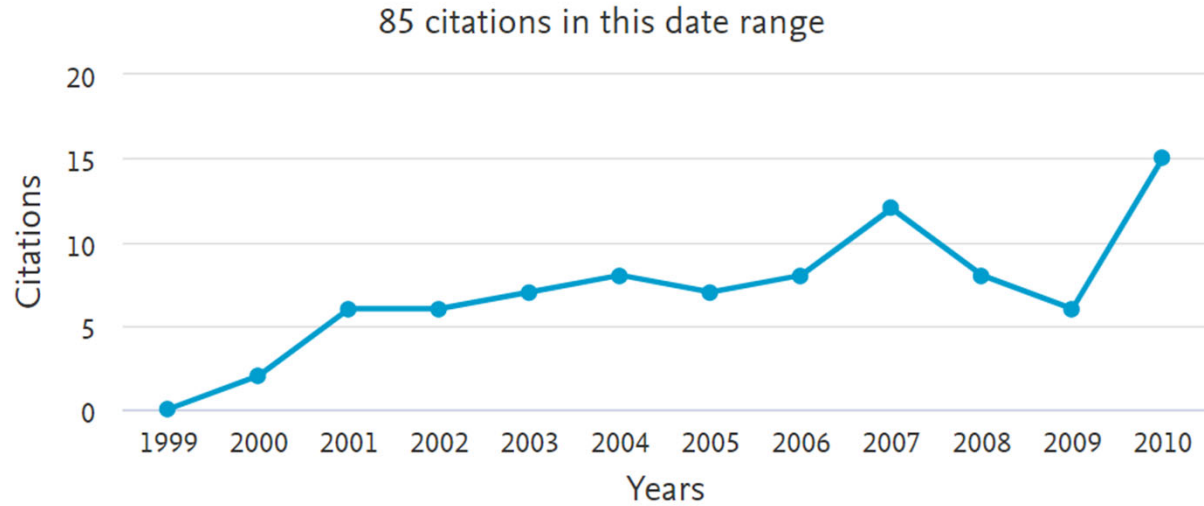


# Citation evaluation

Total citations = 336 (scopus)

Number of citations in recent years shows continued interest in related topics.

Source: scopus



## Influence of the paper

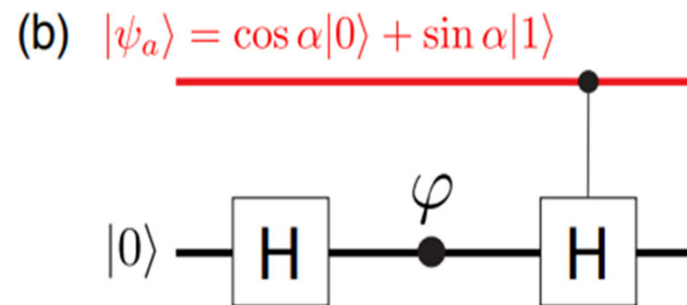
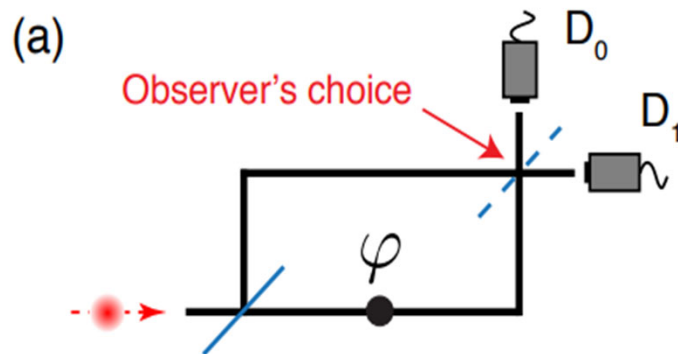
- Sparked debate about the interpretation of data
- Retrocausality
- Popular interpretations: photon travels through both the slits
  - Pilot wave
  - Many-worlds
  - Spontaneous-collapse

Source: What Is Real?: The Unfinished Quest for the Meaning of Quantum Physics by Adam  
Becker



# Delayed Eraser Implementation on a reconfiguration integrated photonic device

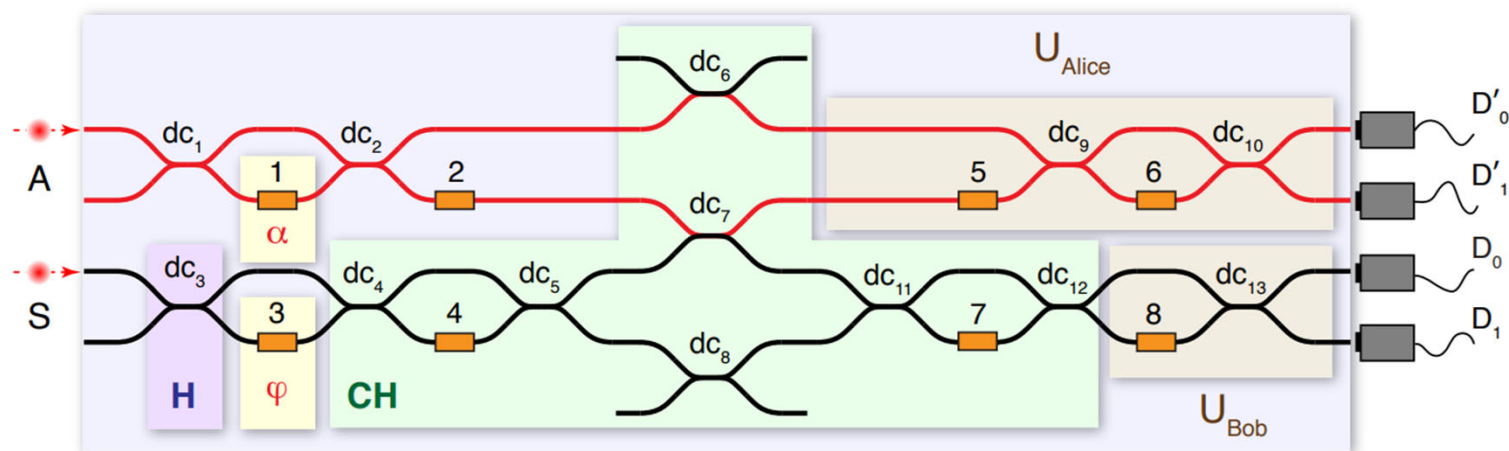
Controlled addition of the second beam splitter using parameter  $\alpha$ .



Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". *Science*. **338** (6107): 634–637

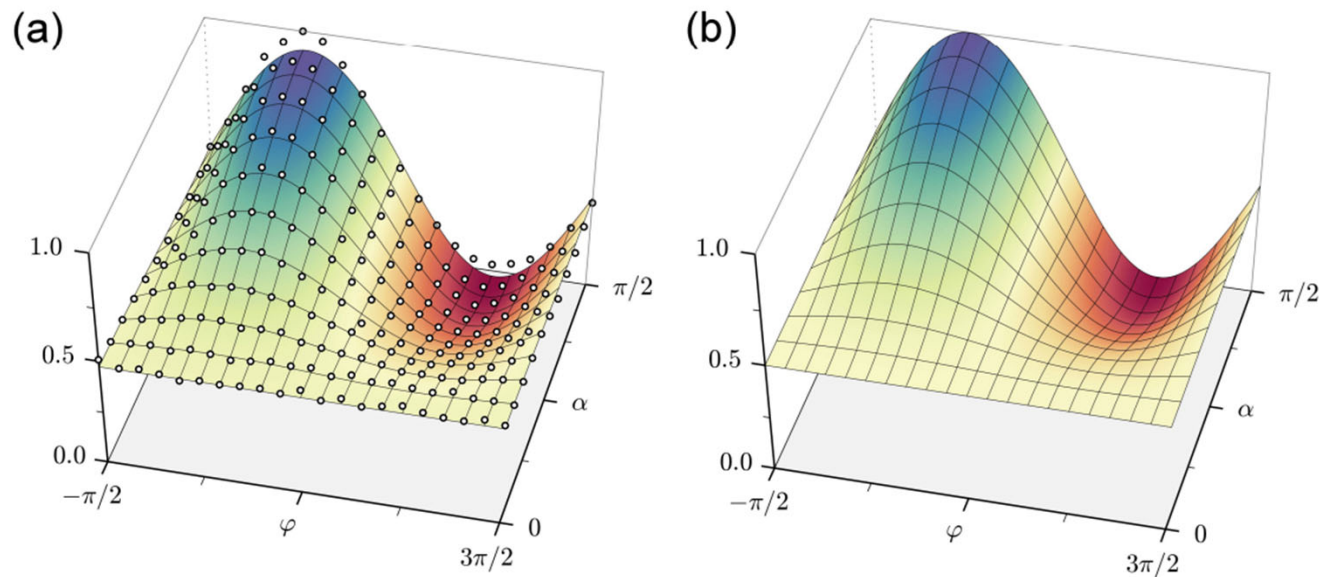
# Delayed Eraser Implementation on a reconfiguration integrated photonic device

Experimental setup where H  $\rightarrow$  hadamard, CH  $\rightarrow$  controlled hadamard.



Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". *Science*. **338** (6107): 634–637

# Delayed Eraser Implementation on a reconfiguration integrated photonic device



(a) Measured data  
(b) Simulated data

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". *Science*. **338** (6107): 634–637

# Delayed Eraser Implementation on a reconfiguration integrated photonic device

- Delayed choice of Wheeler's proposal is replaced by a quantum controlled beam-splitter followed by a Bell inequality test.
- Continuous tuning between particle and wave measurements
- Maximal violation of Bell inequality
- Photon could not have known in advance whether to behave as a wave or a particle.

Peruzzo, Alberto; Shadbolt, Peter J.; Brunner, Nicolas; Popescu, Sandu; O'Brien, Jeremy L. (2012). "A quantum delayed choice experiment". *Science*. **338** (6107): 634–637

# Summary

- Wheeler's thought experiment to determine whether photons somehow know the information about the experimental apparatus continues to provoke interpretations.
- Sean Carroll in his blog calls it "The Notorious Delayed-Choice Quantum Eraser."
- Experimentally, using entangled photons to show the behaviour was the key achievement of Kim et al. (2000).