A Photon Switch For Interaction-Free Measurement

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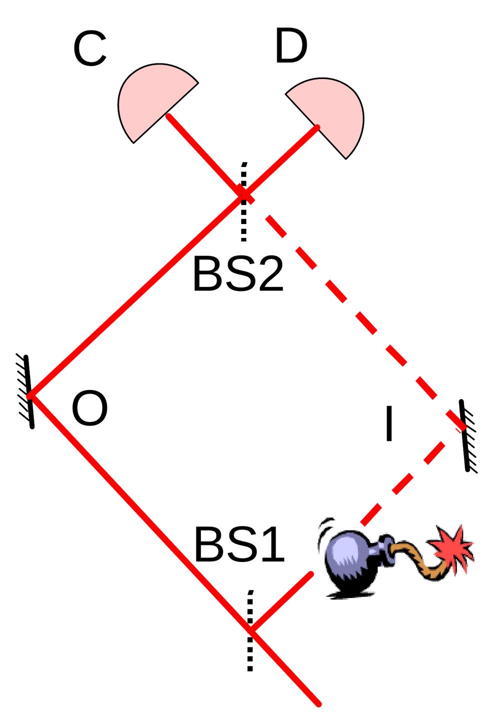
Motivation

- To experimentally demonstrate a contradiction between classical reasoning and quantum mechanics.
- An application of a recently developed 2-photon switch.

Interaction-Free Measurement

A. C. Elitzur, and L. Vaidman, Found. Phys. **23**, 987 (1993)



Bomb Absent:
Only detector C fires

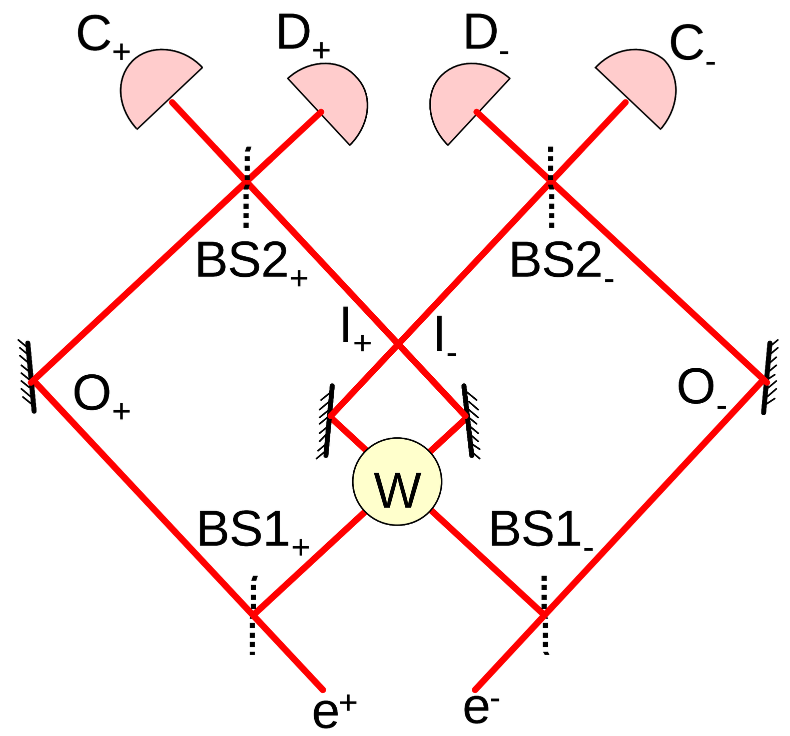
Bomb Present:

Detector	Prob.	Result
C	¼	None
D	¼	Present
Neither	½	Bang

- A normal Mach-Zehnder interferometer is constructed so that 100% of the particles exit towards detector C.
- A highly sensitive bomb is placed in arm I so that if only one particle hits it it explodes.
- Interference has now been disrupted by the presence of the bomb.
- Consequently, a particle that enters the interferometer can be detected at D with probability equal to 1/4.
- A detection at D would indicate the presence of the bomb without exploding it.
- What would happen if the bomb was in superposition of being in and out of the interferometer?

Hardy's Paradox

L. Hardy, Phys. Rev. Lett. **68**, 2981 (1992)

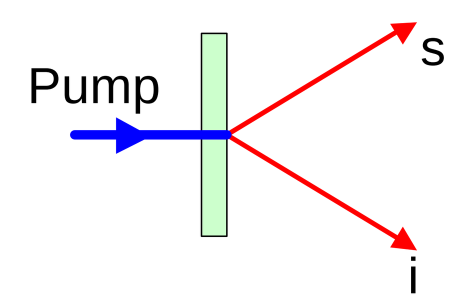


Outcome	Prob
D_+ and C_-	1/16
D_- and C_+	1/16
C_+ and C_-	9/16
D_+ and D_-	1/16
Explosion	4/16

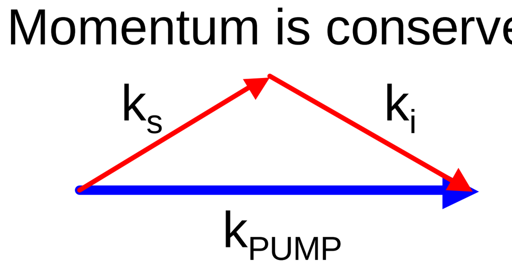
- Consider two overlapping Mach-Zehnder interferometers, one containing an electron and the other a positron.
- If both particles pass through region W simultaneously they annihilate each other.
- Each interferometer is an Interaction-Free Measurement (IFM) on the particle in the other interferometer; e.g., D_- can only fire if the e^+ was at W.
- Quantum mechanics predicts that 1/16 of the time both IFM's will simultaneously indicate the presence of their respective target particle at W.
- The paradox is that this implies that the particles should have annihilated at W, but instead they were detected at D_- and D_+.

Spontaneous Parametric Downconversion

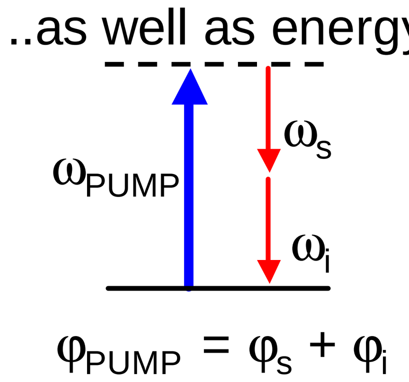
Downconversion



Momentum is conserved..



..as well as energy

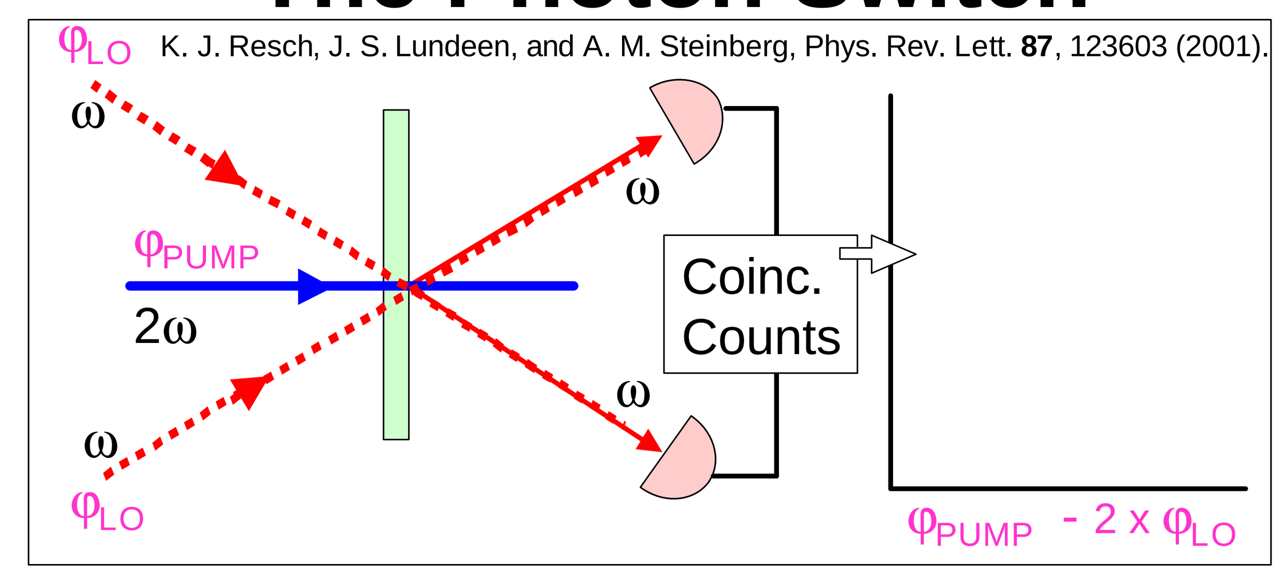


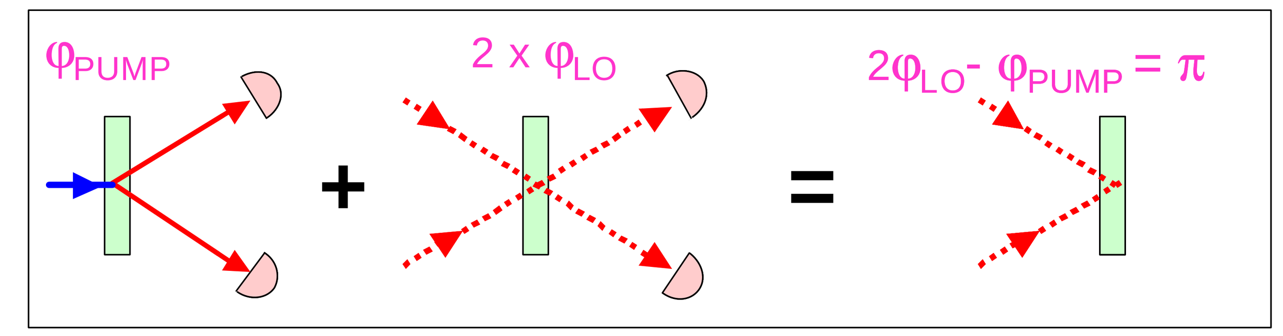
$\varphi_{PUMP} = \varphi_s + \varphi_i$

- A pump photon is spontaneously converted into two lower frequency photons in a material with a nonzero $\chi^{(2)}$

The Photon Switch

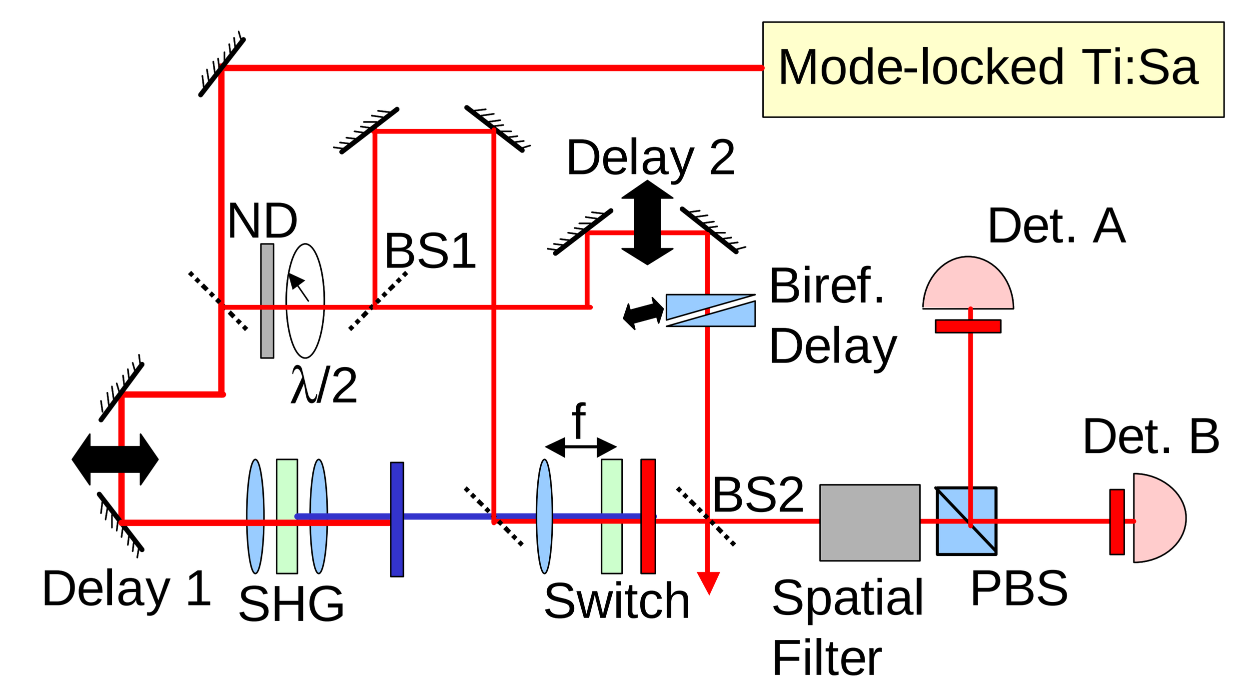
K. J. Resch, J. S. Lundeen, and A. M. Steinberg, Phys. Rev. Lett. **87**, 123603 (2001).





- The switch allows photon pairs to upconvert 100% of the time – effectively annihilating each other.

Experimental Setup



Minimum switch efficiency required = 75%

Conclusions

- An experimental implementation of Hardy's Paradox is now possible.
- A single-photon level switch allows photons to interact with high efficiency.
- A later extension will look at the results of weak measurements in Hardy's Paradox.

Walter C. Sumner Foundation
NSERC CRSNG
Canada Foundation for Innovation
Fondation canadienne pour l'innovation