Causation in the Quantum World — A New Case for the Paris Option?

Huw Price

Collège de France :: December 5, 2013

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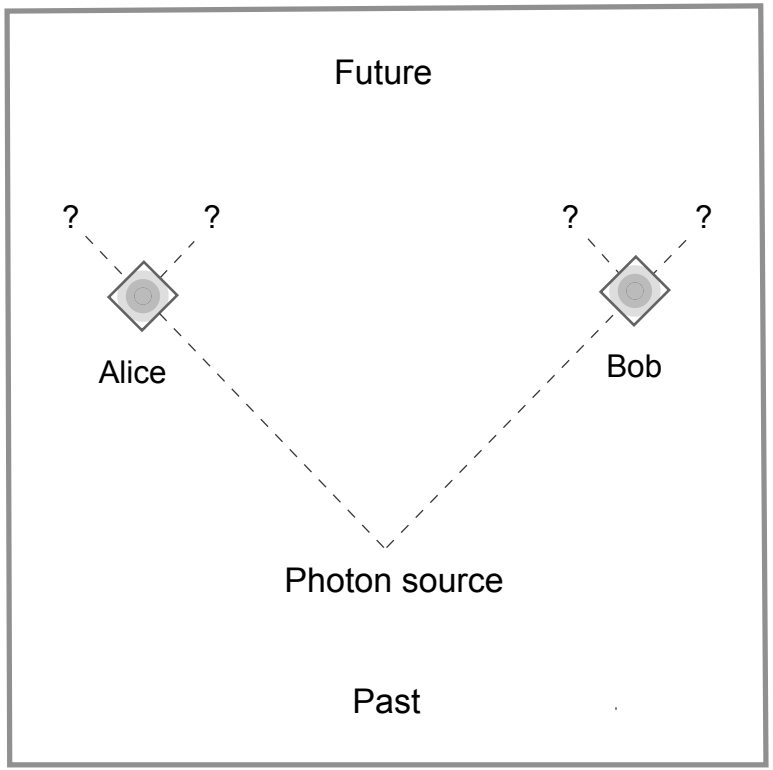

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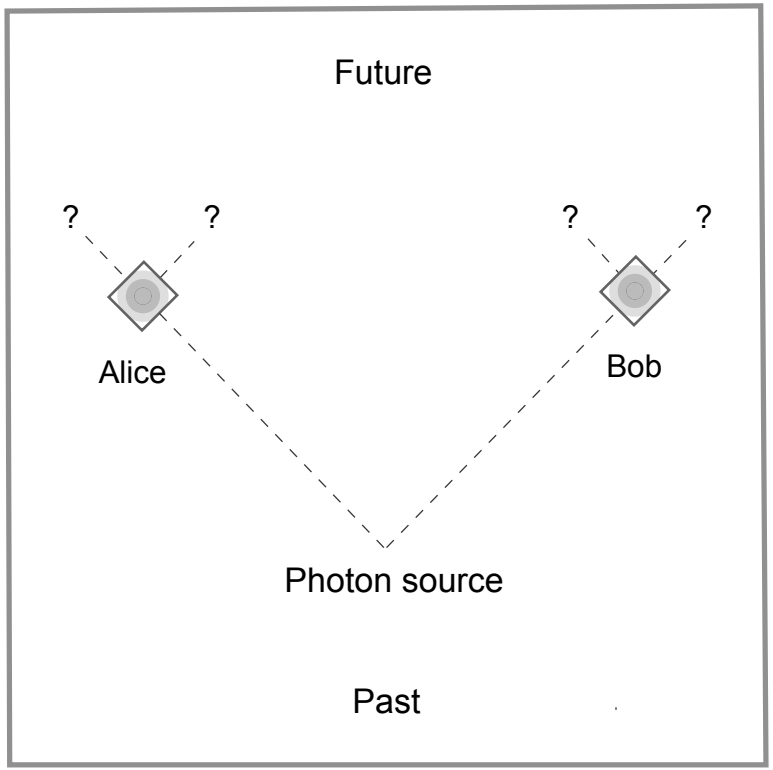

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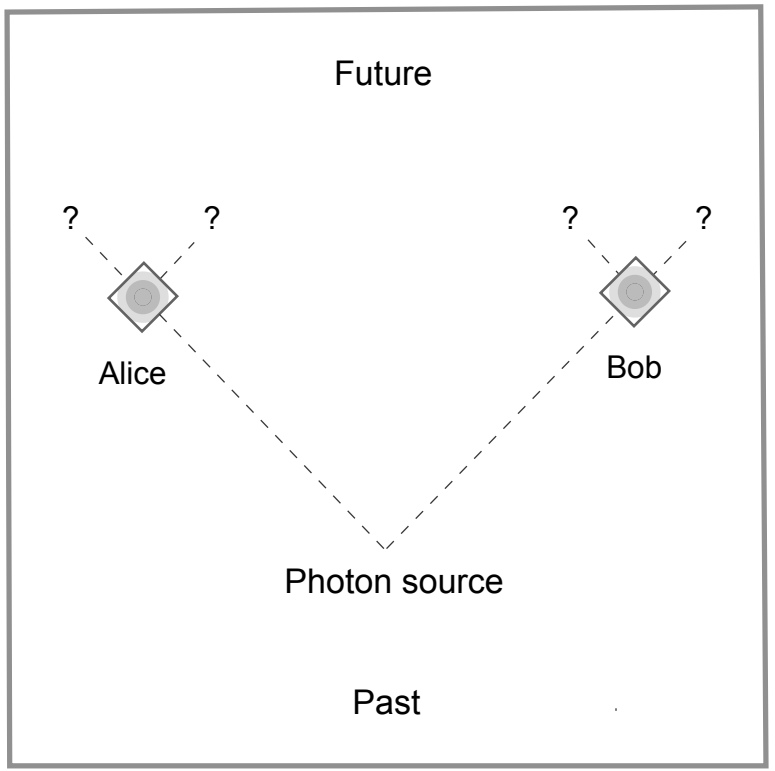

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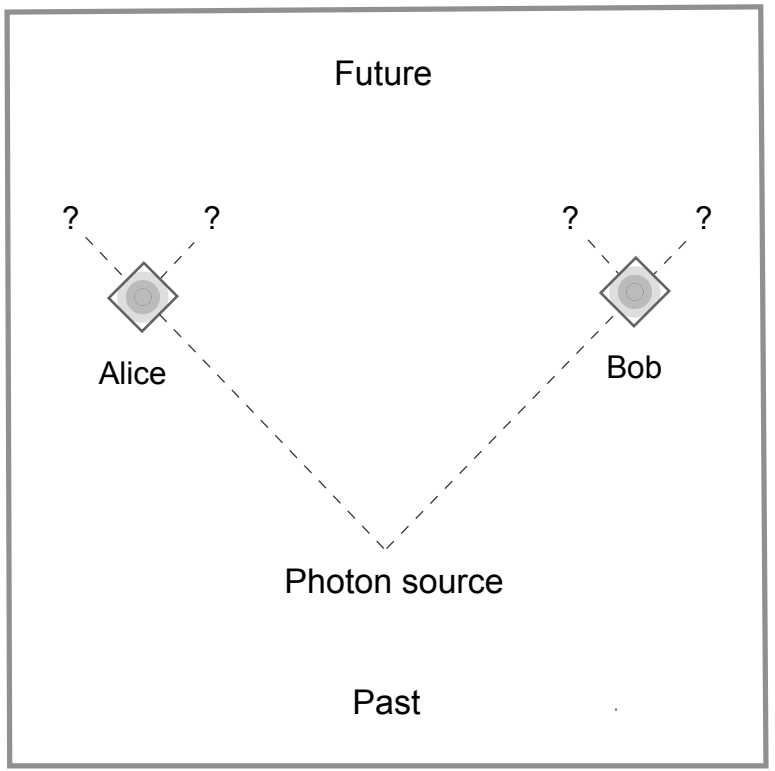

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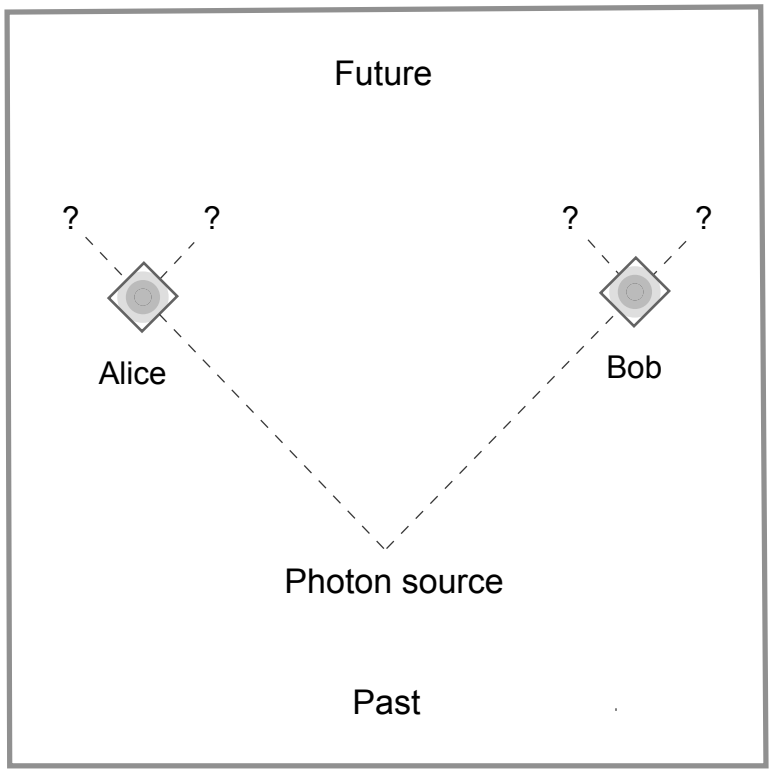

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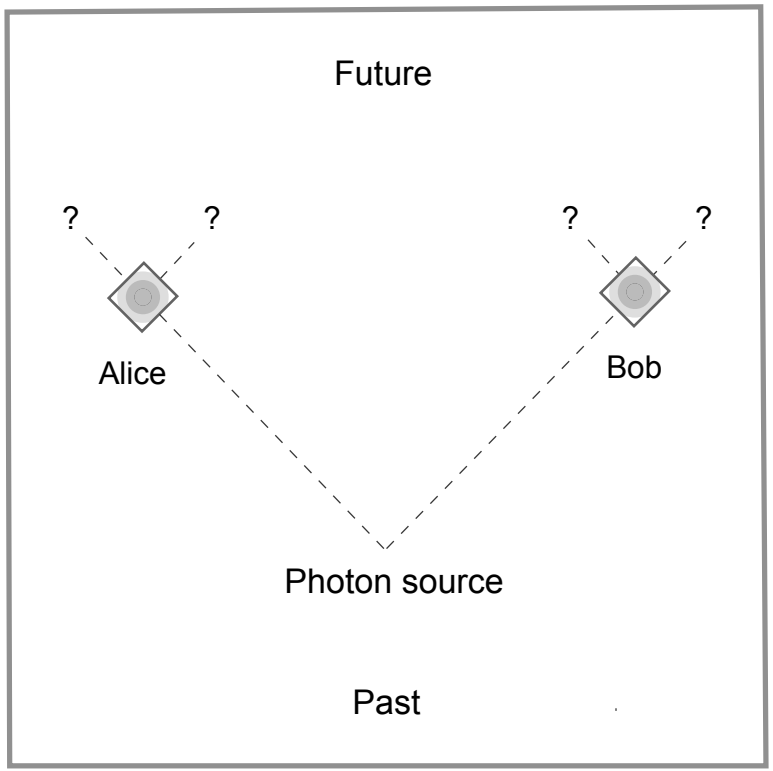

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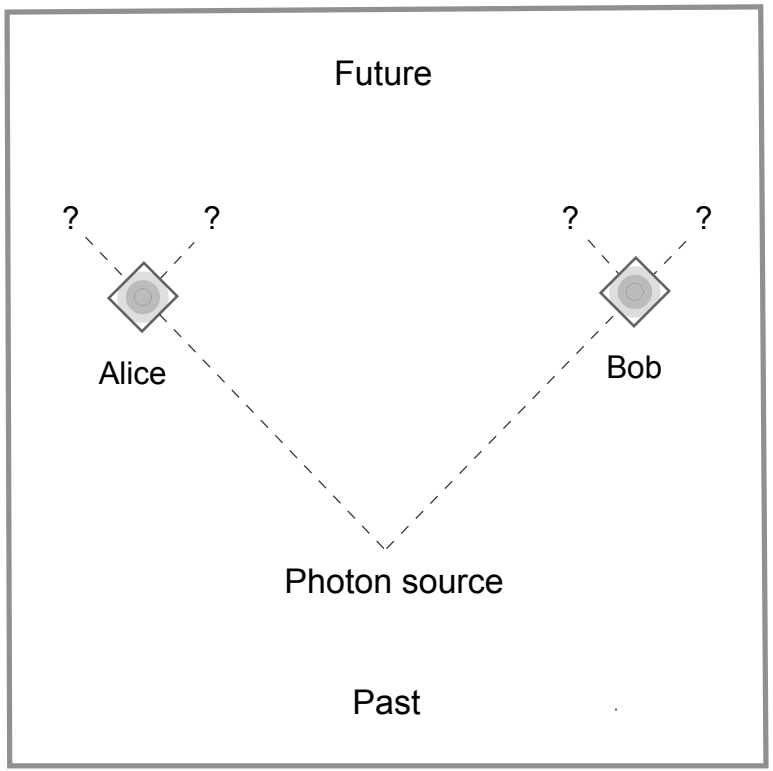

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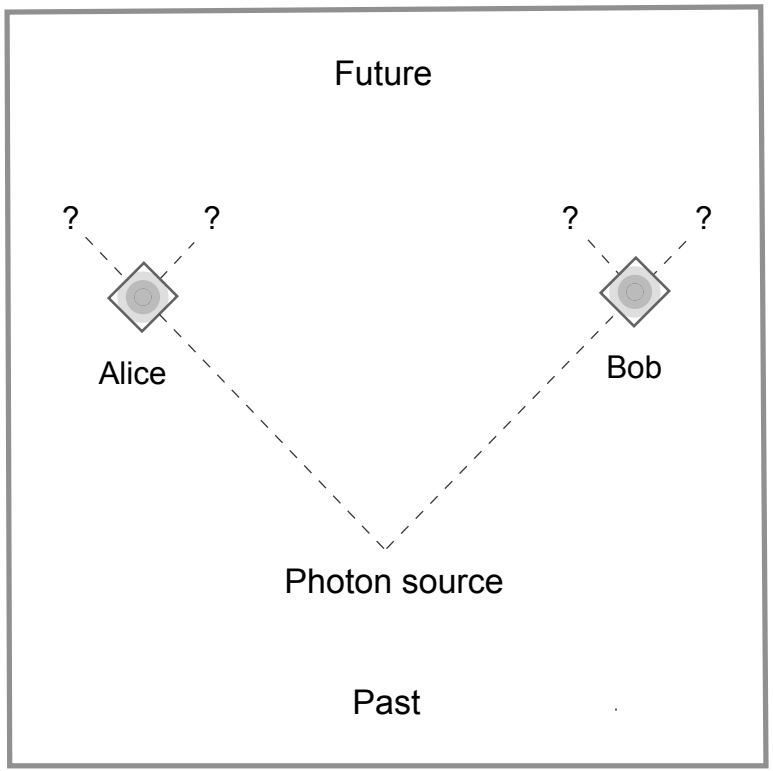

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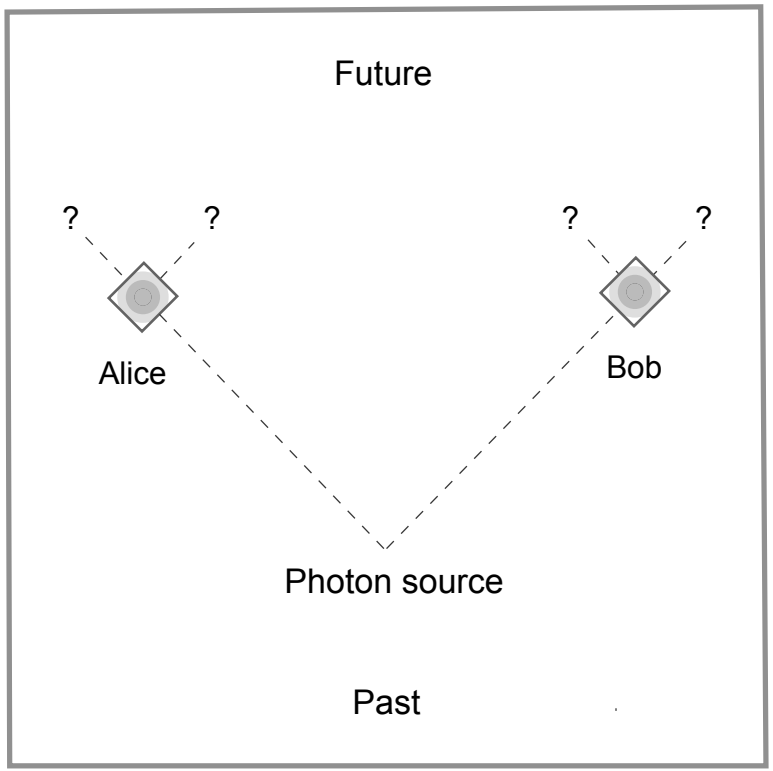

The Parisian zigzag

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- But in the late 1940s a Parisian graduate student – shown here with his advisor – spotted a loophole: he saw that Alice's choices could affect Bob's particle (and *vice versa*), **without action at a distance**, if the effect followed a zigzag path, **via the past**.

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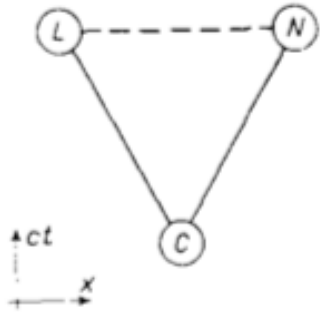

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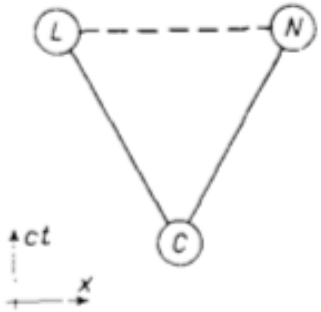

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- However, it may be the key to saving Locality, in the face of Bell's Theorem.

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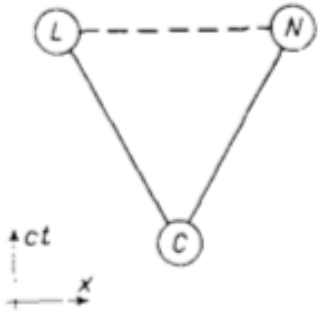

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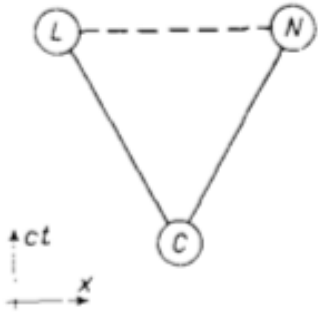

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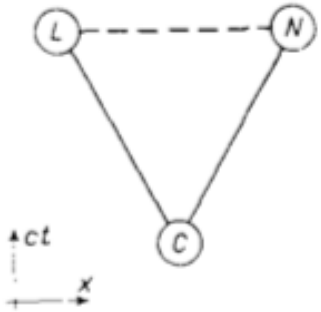

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Bell's Theorem and retrocausality

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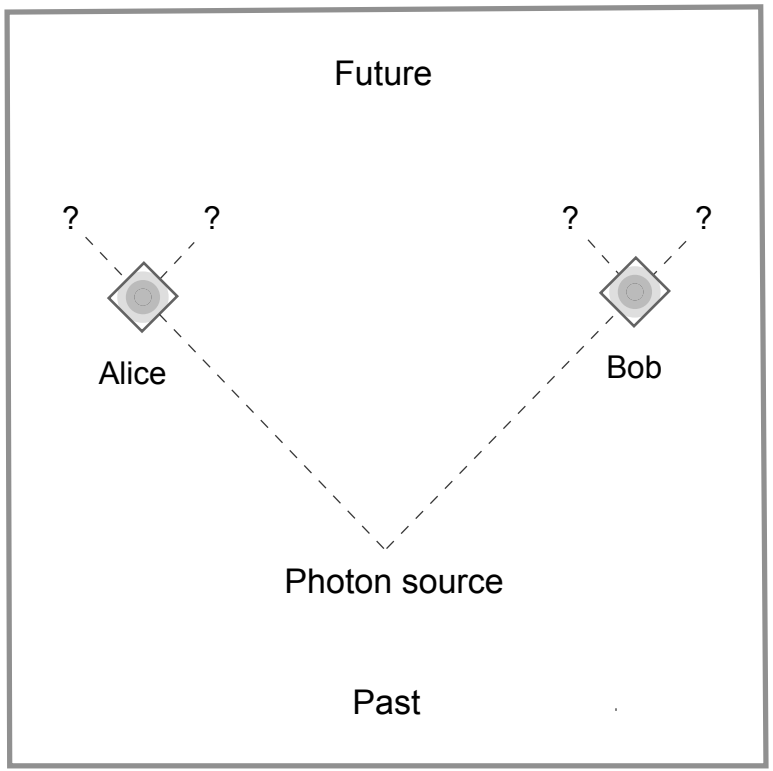
- The Bell correlations are easy to explain, in principle, if we allow such 'retrocausality' – i.e., if we allow the Parisian zigzag.
- In effect, we save Locality (i.e. 'no action at a distance'), and the tension with relativity vanishes.
- **Question:** So why isn't the Parisian zigzag more popular?



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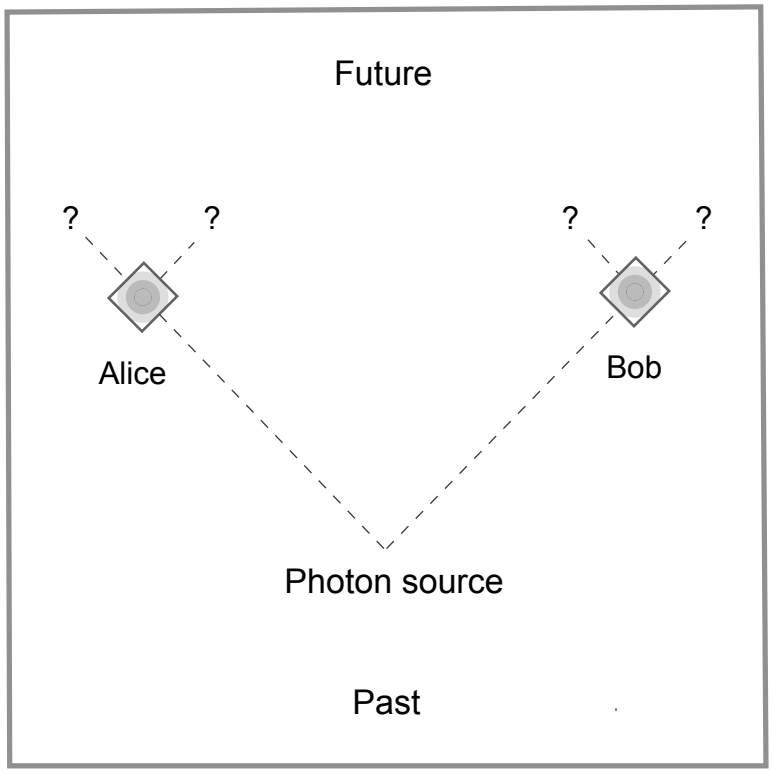

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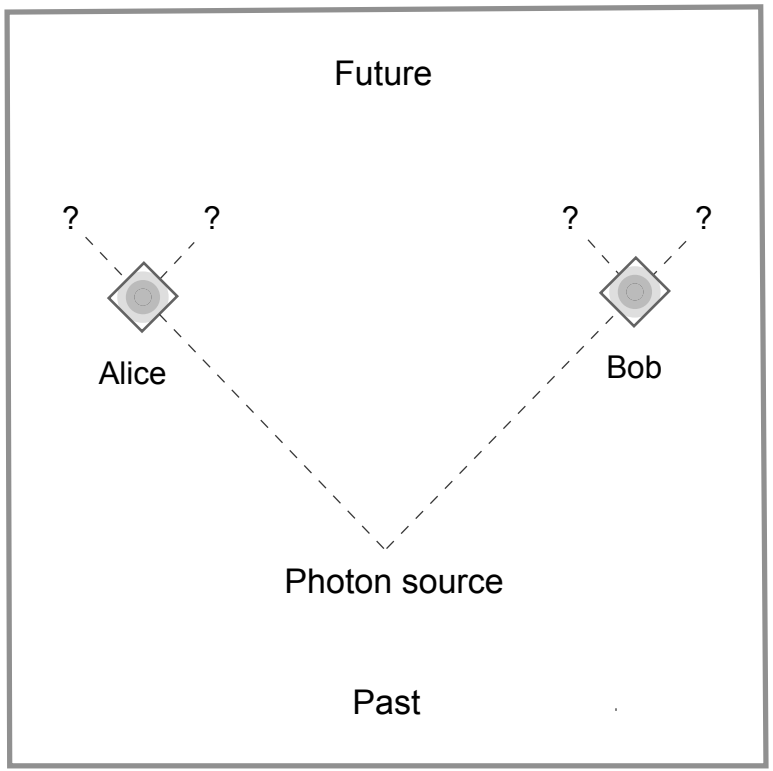

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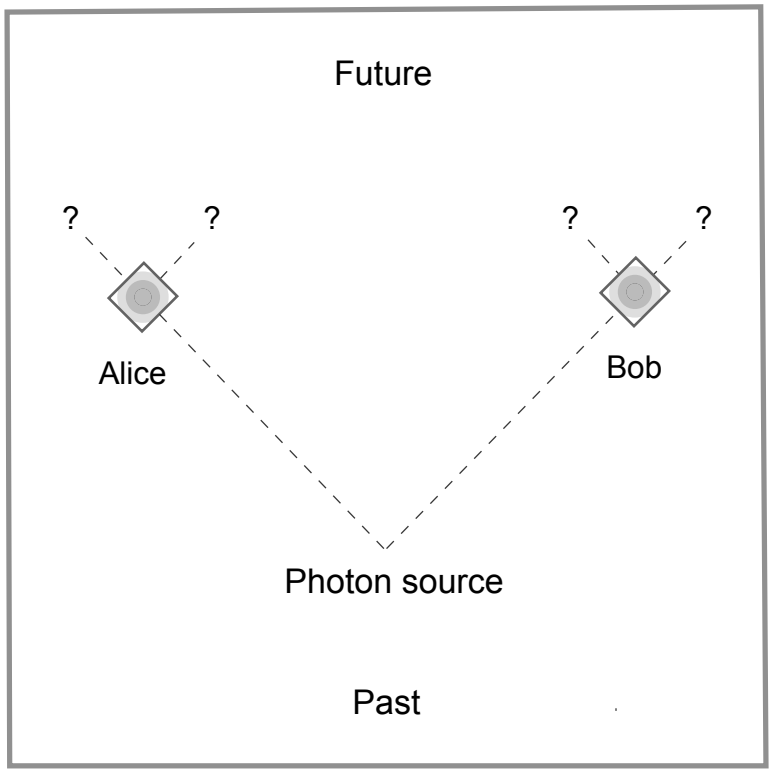

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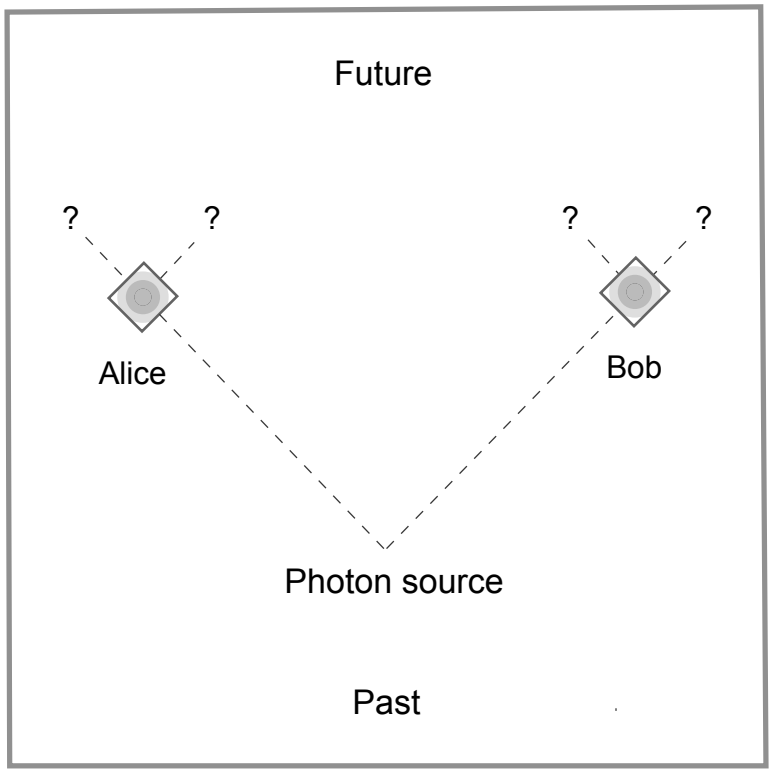

Bell's own answer

ge.infn.it/ zanghi/quotes.html

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CERN 1988 June 8

I have not myself been able to make any sense of the notion of backward causation. When I try to think of it I lapse quickly into fatalism.

John Bell

Other common objections

Common responses to the retrocausal proposal:

1. "Show me a model"
2. "Retrocausality implies retrosignalling, and that leads to paradoxes".

Later, I want to show that we can do something to respond to these objections.

But first: A new argument for retrocausality in QM, which could in principle have been discovered long **before** the EPR argument.

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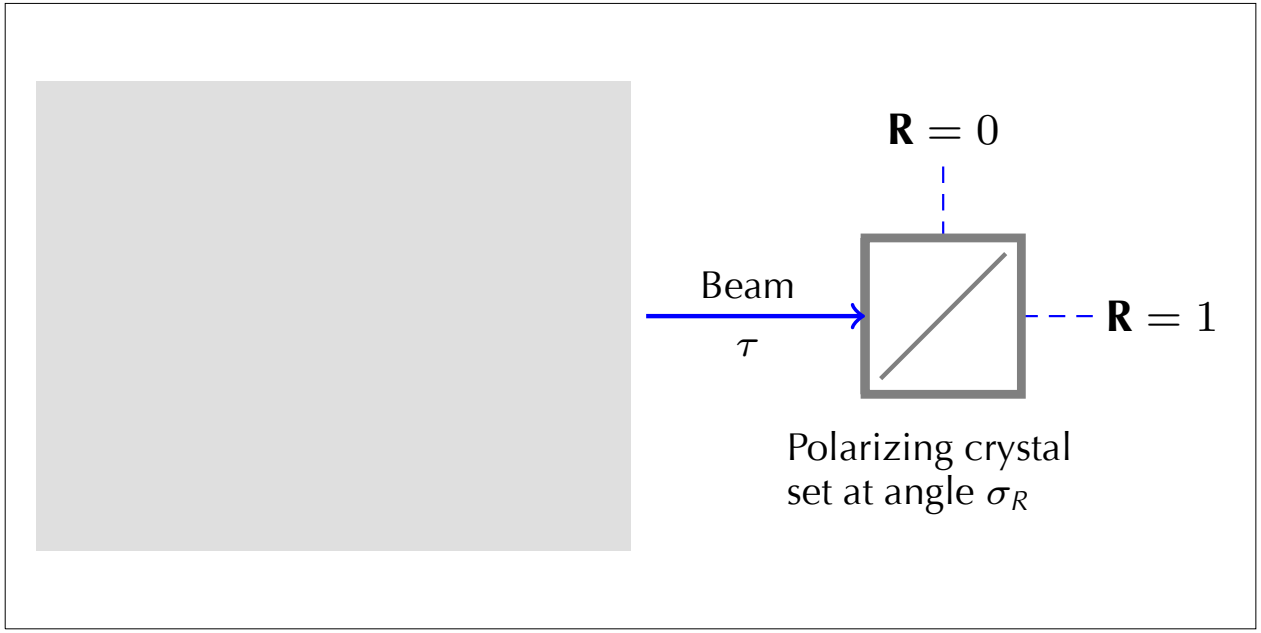

Malus' Law: $\text{Intensity}_{\mathbf{R}=1} = \cos^2(\tau - \sigma_R)$, $\text{Intensity}_{\mathbf{R}=0} = \sin^2(\tau - \sigma_R)$

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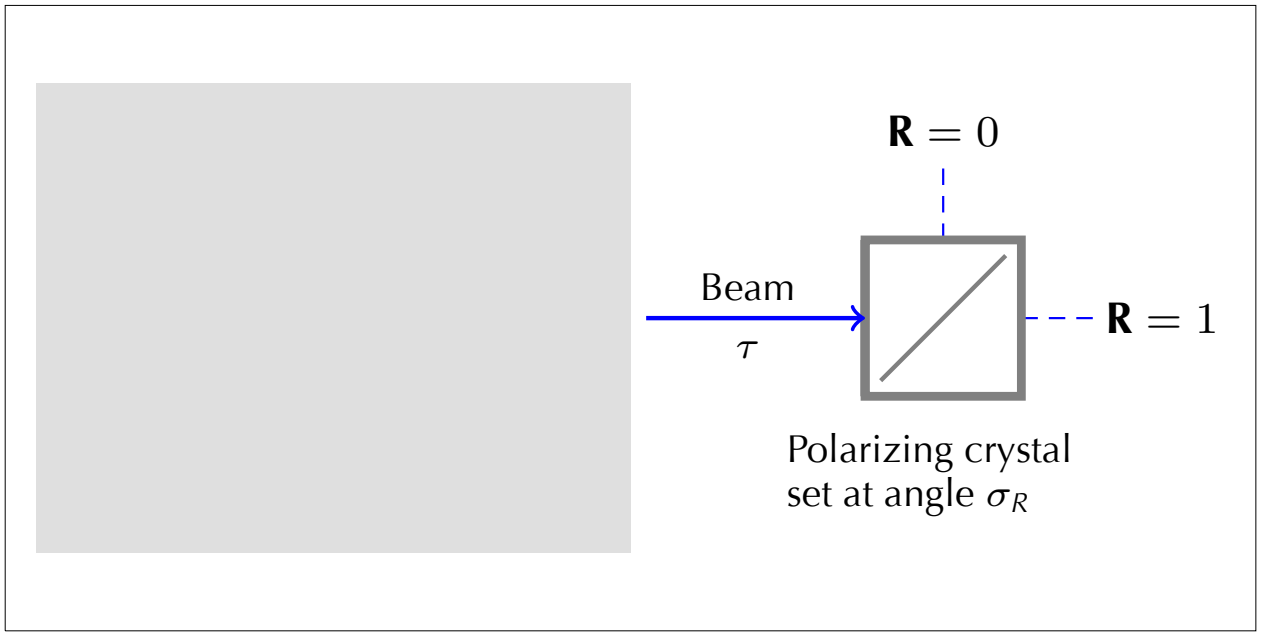

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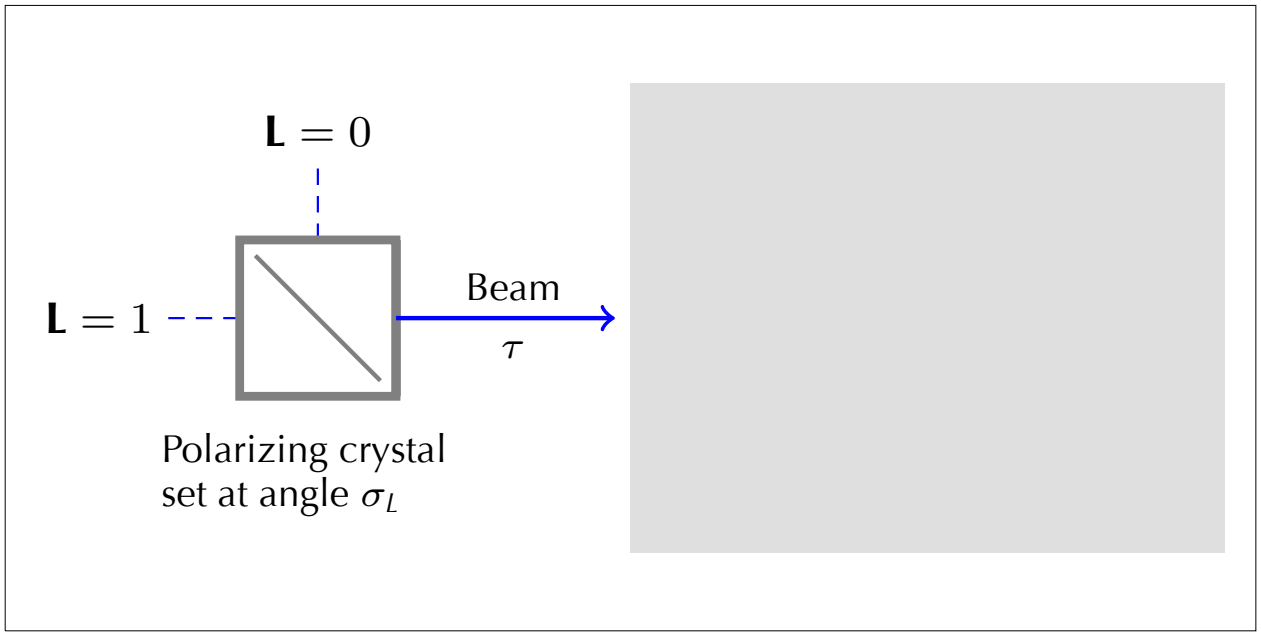

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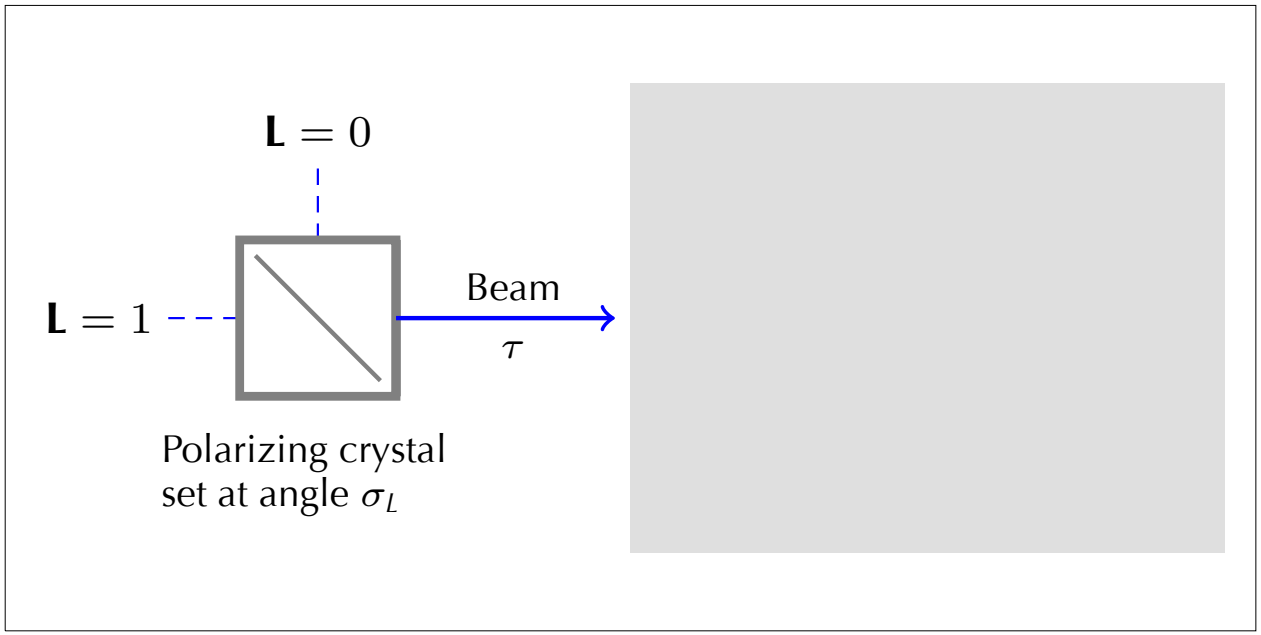

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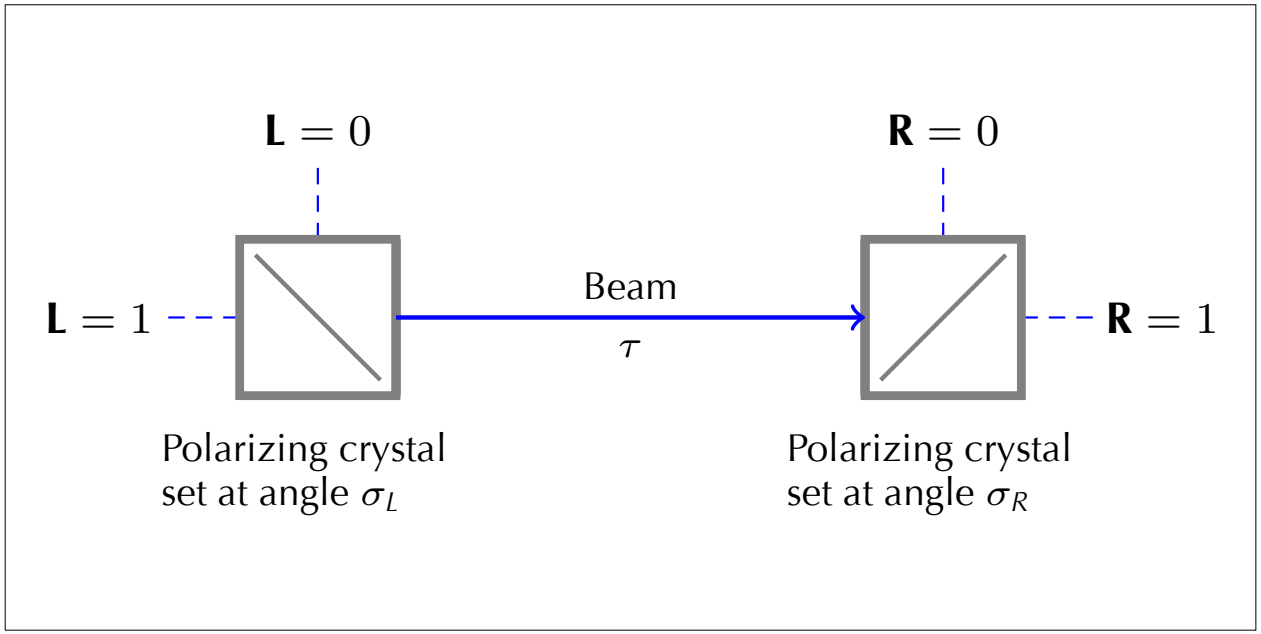
Thinking about connection and control



1. Polarization as a 'local' mechanism
2. What we can wiggle

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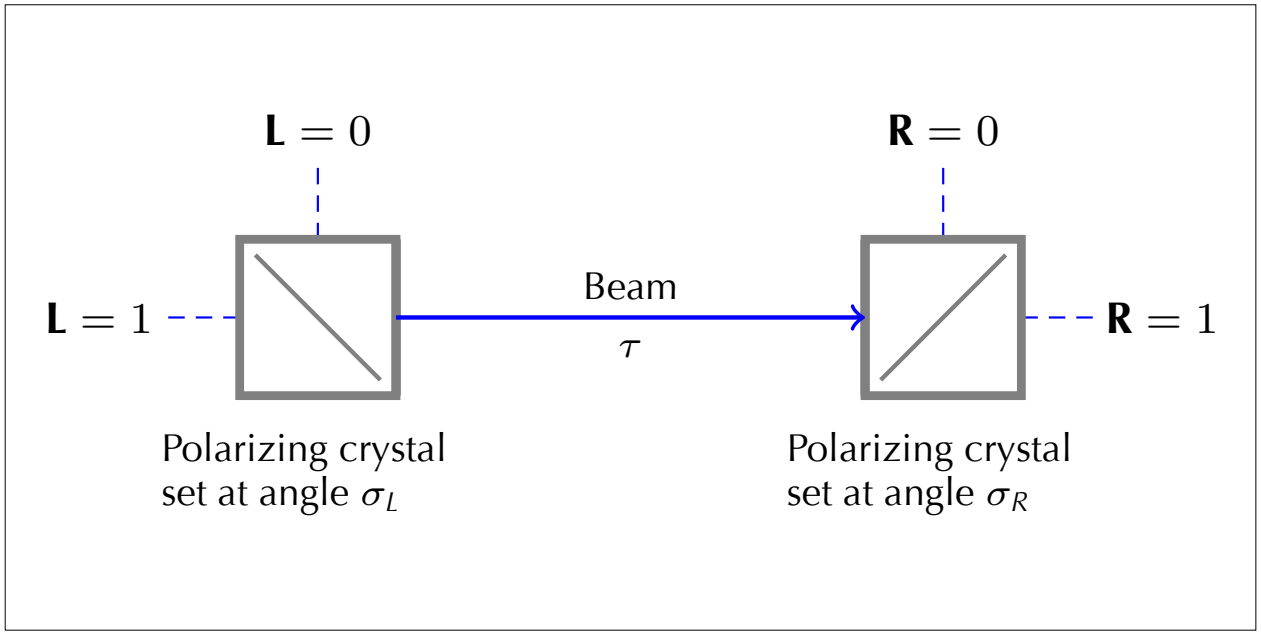

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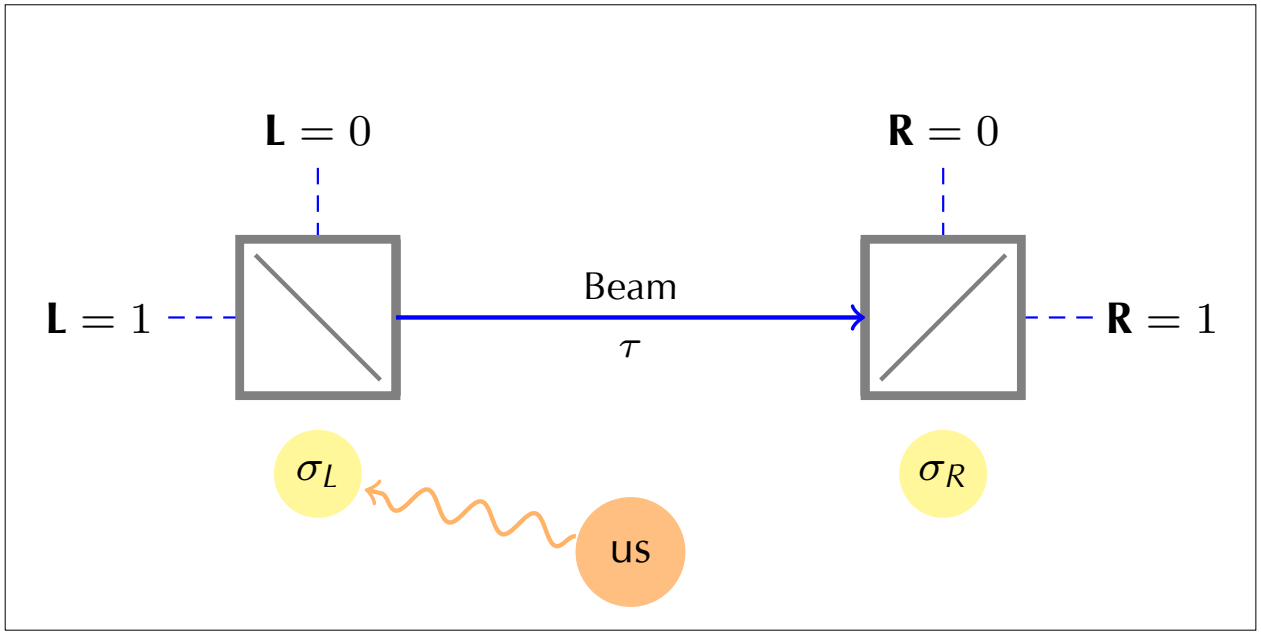

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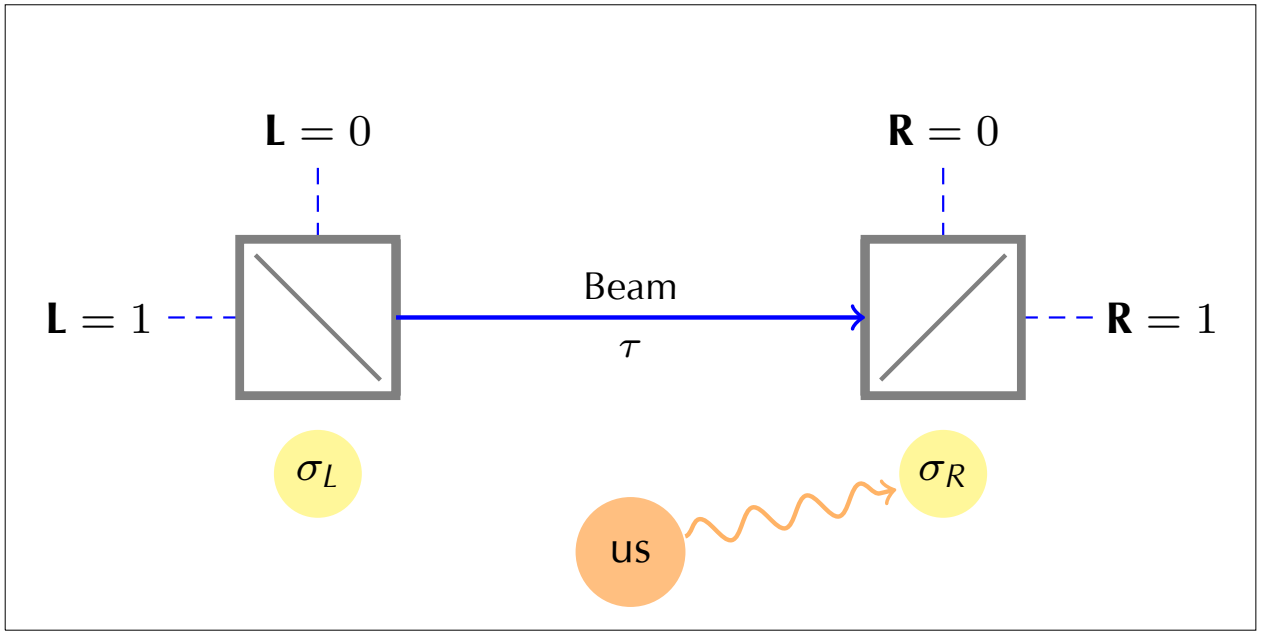

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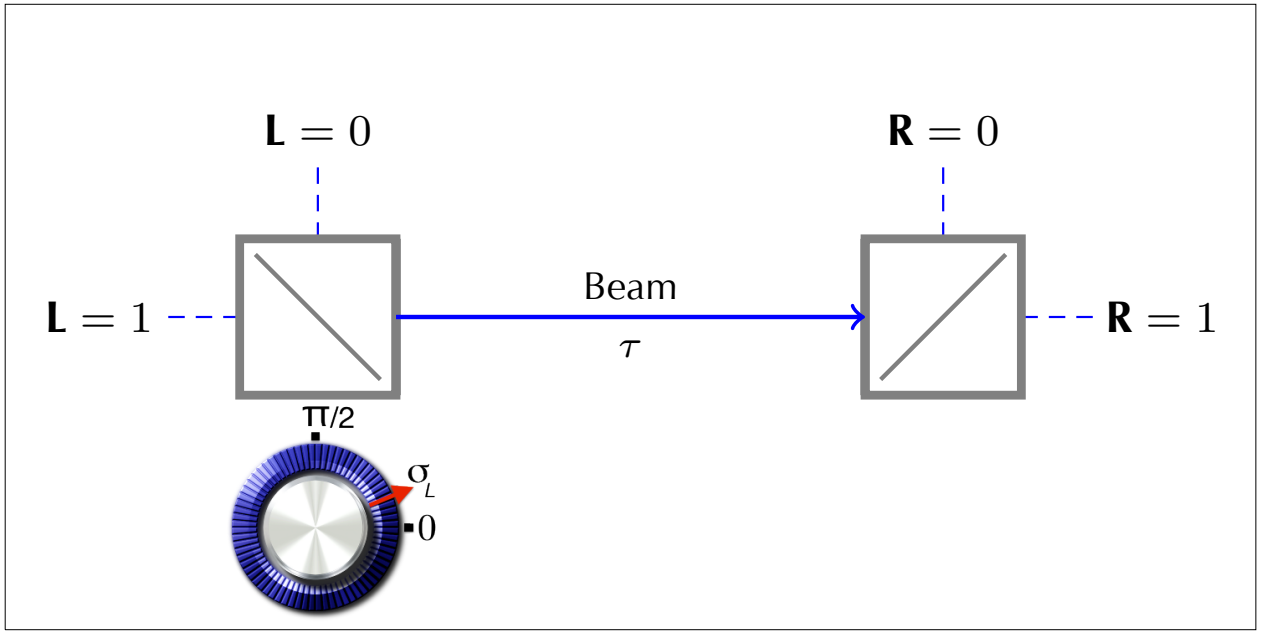
Defeating the Demon of the Left?



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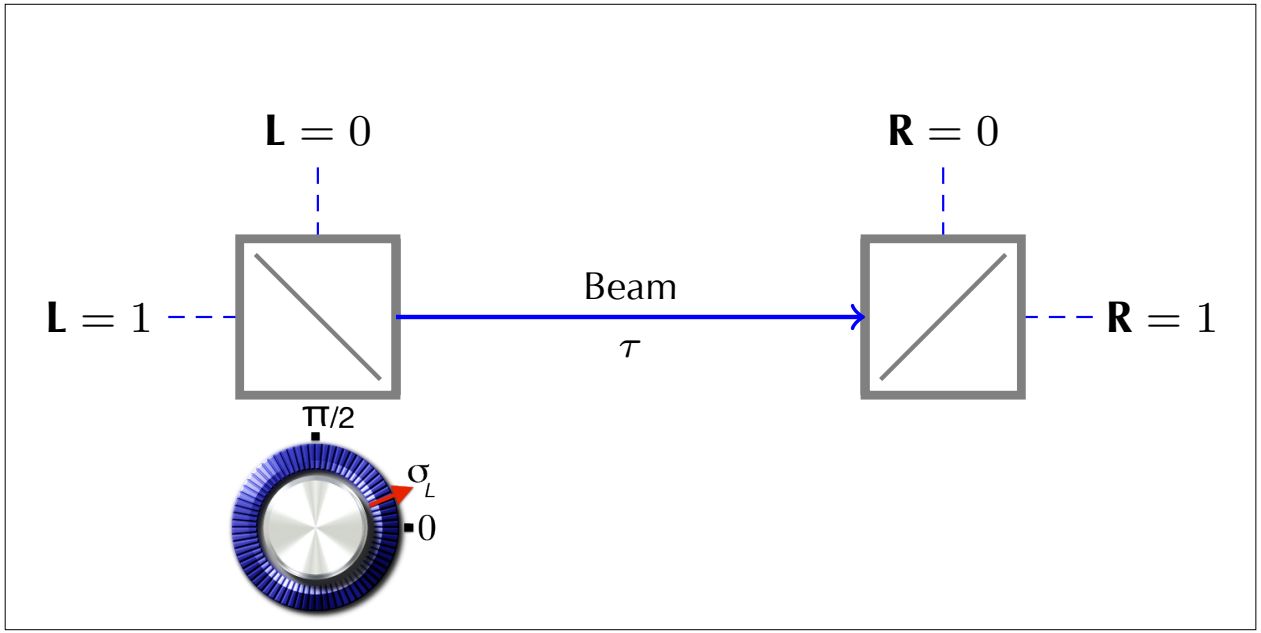

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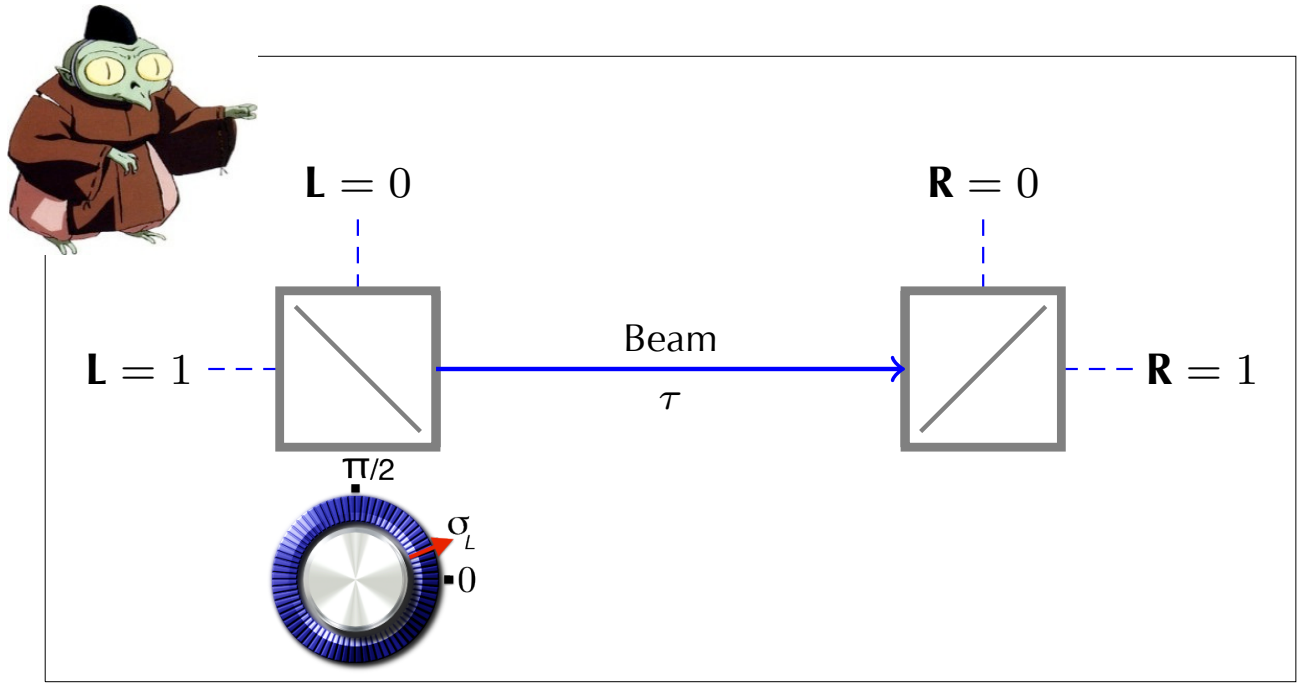

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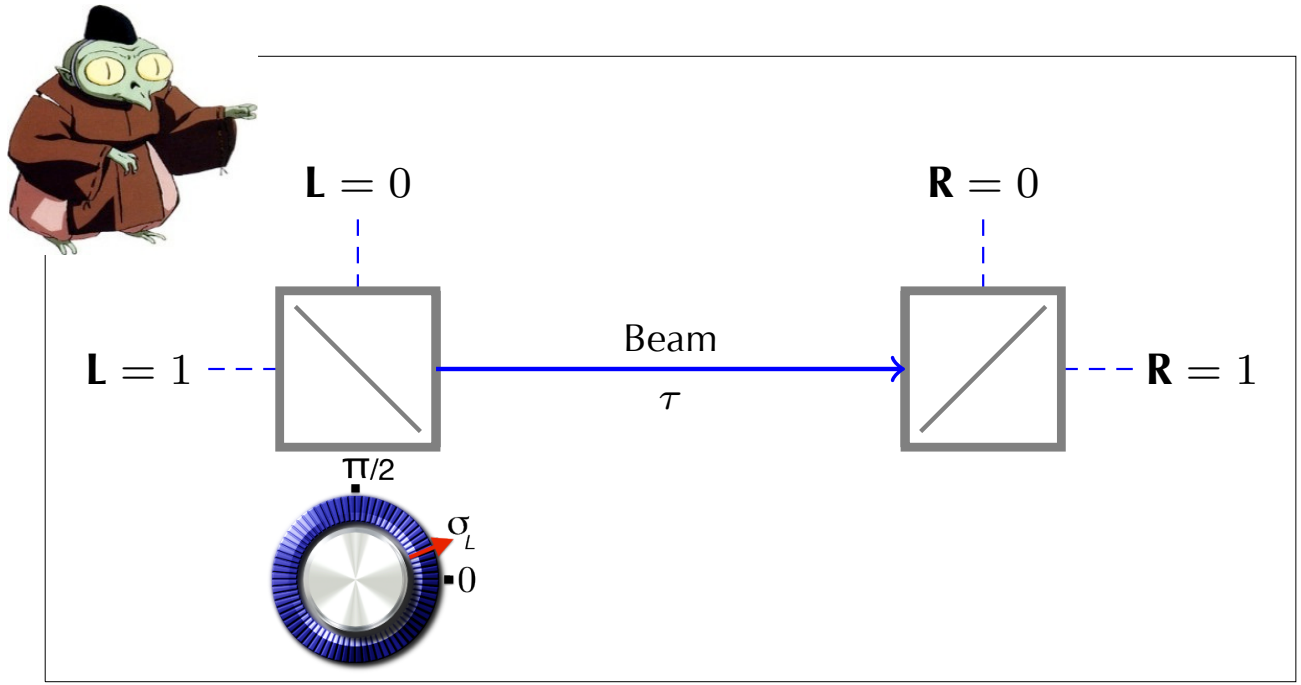

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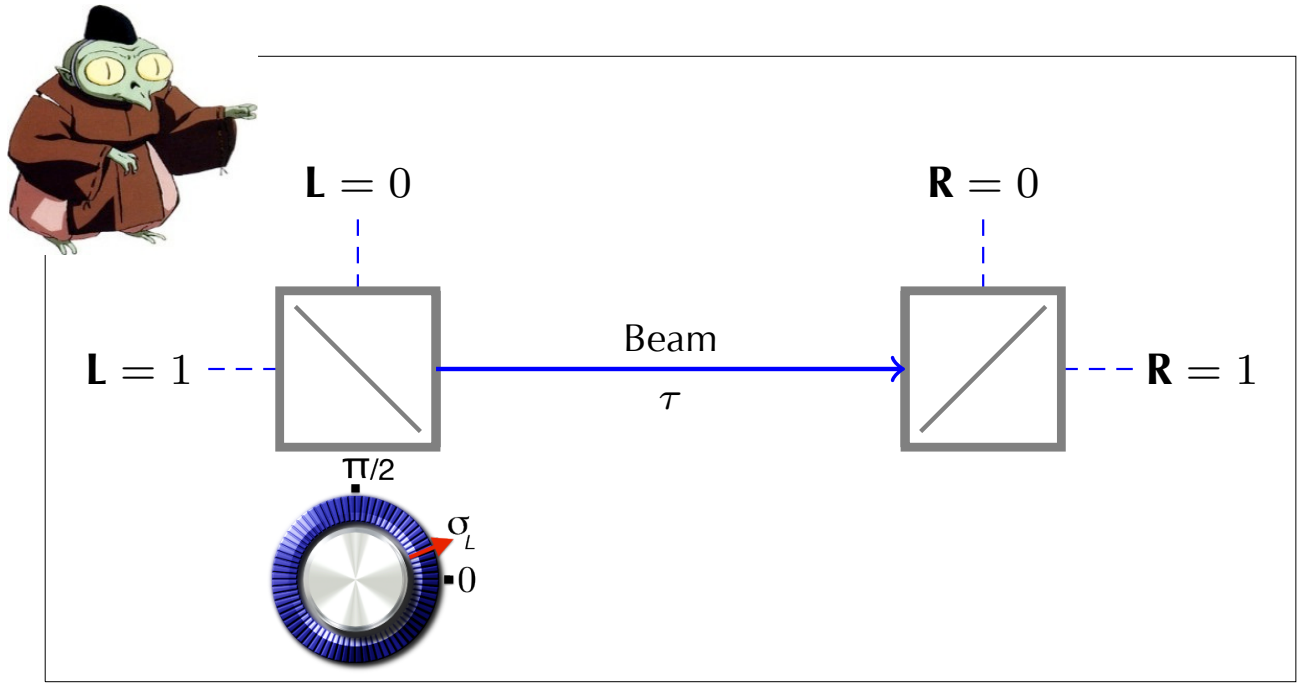

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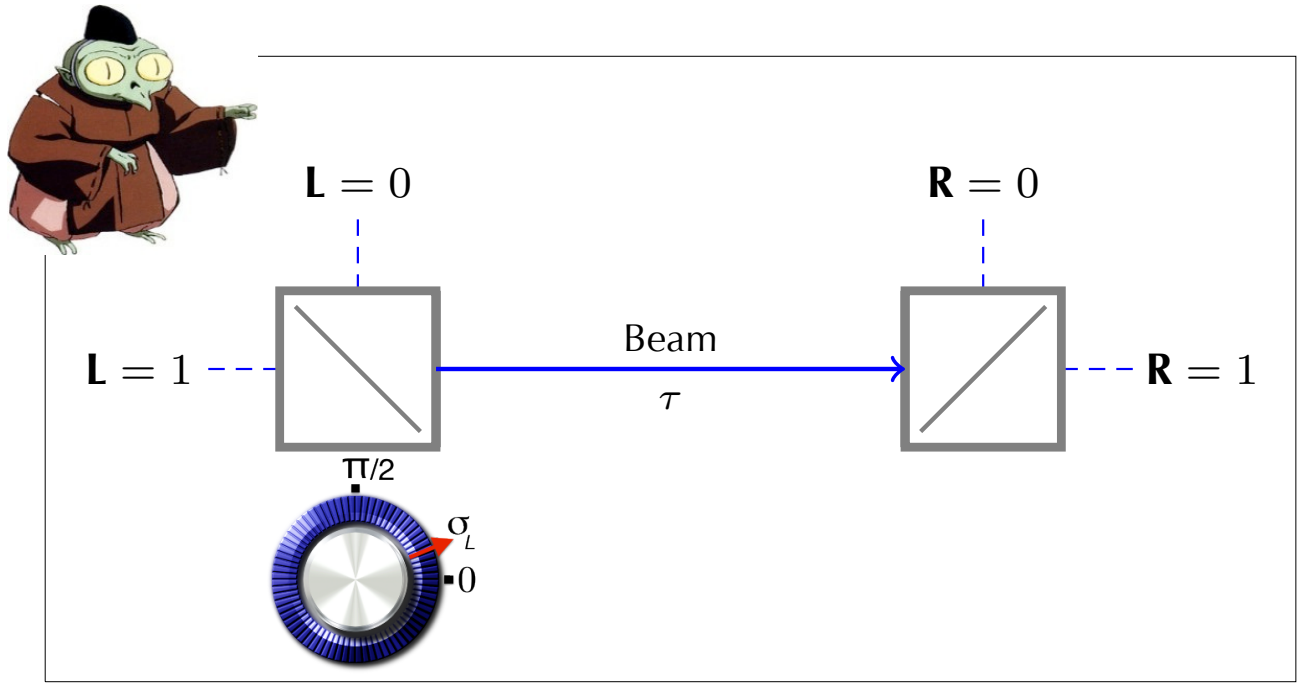

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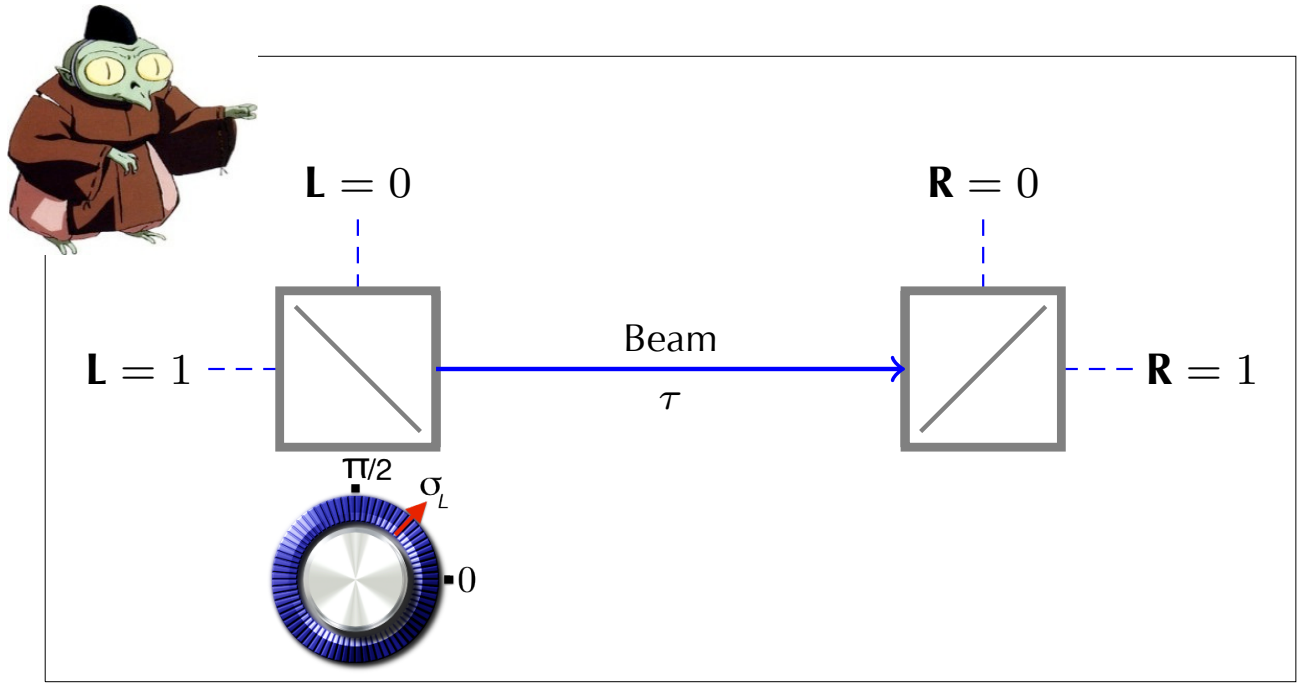

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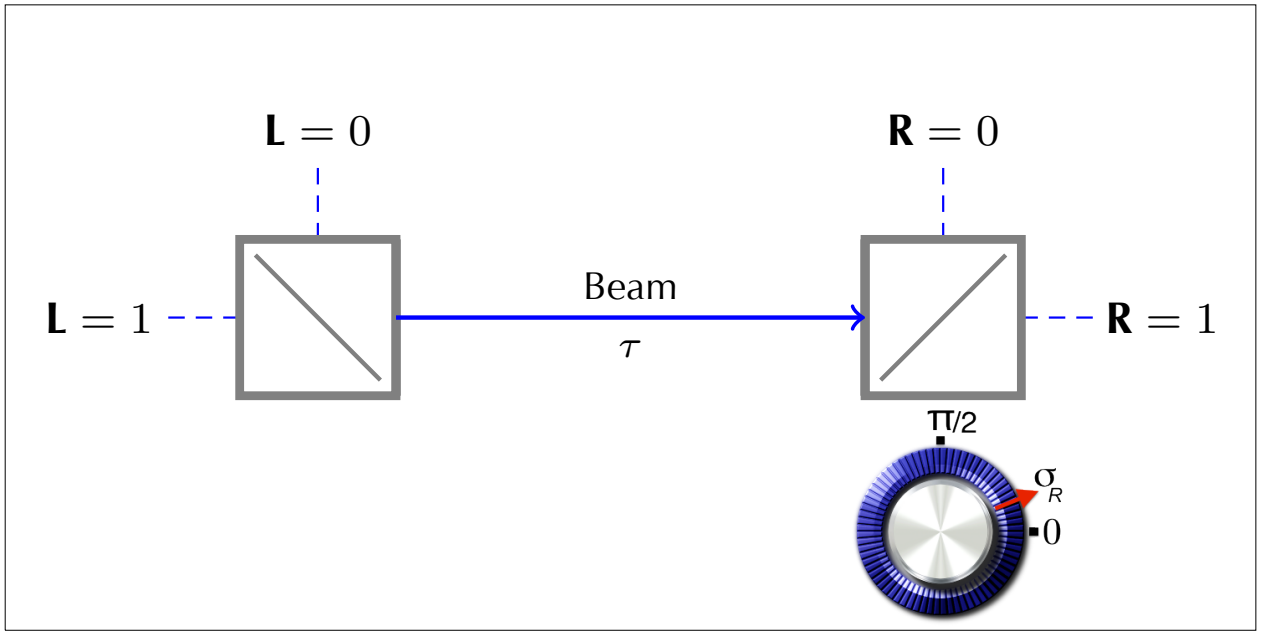

- Similarly, suppose we control the **right** polarizer angle, σ_R, but not the output beams – **Nature** controls those. Can we control the input polarization, τ?
- **No.** Nature absorbs our wiggles in changes in the output intensities, and τ doesn't change. (So no **retrocausality** here!)

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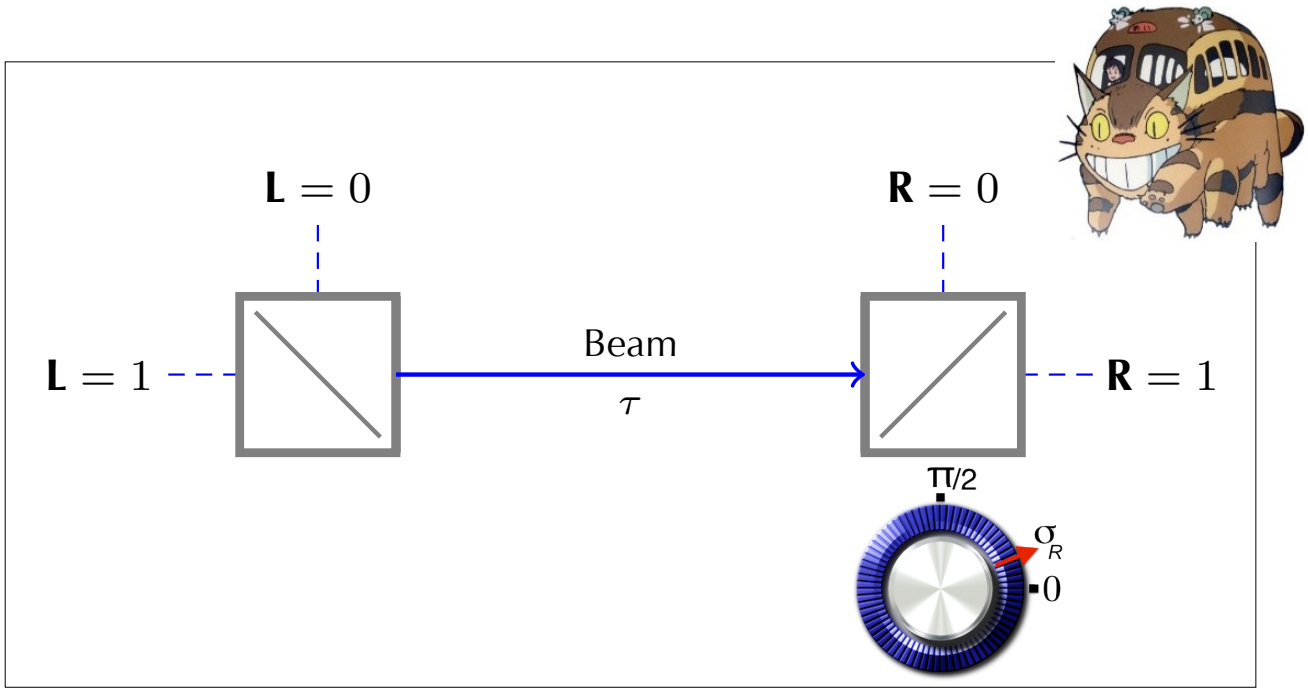

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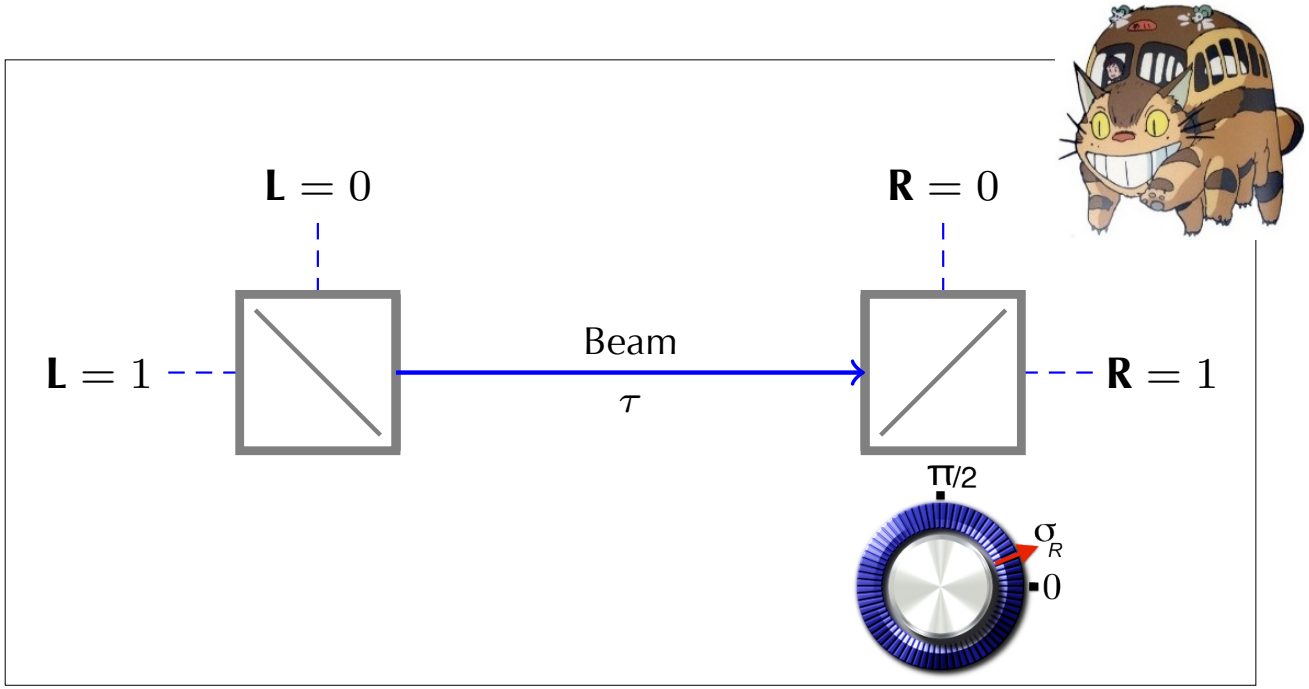

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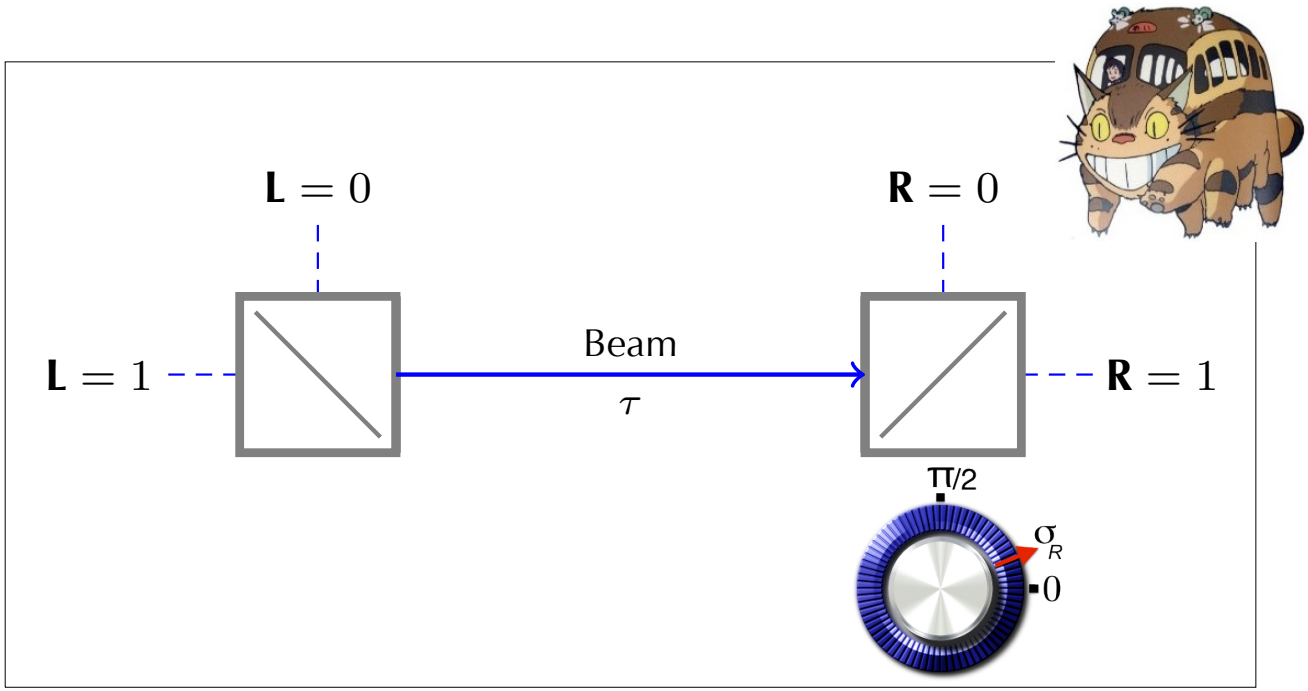

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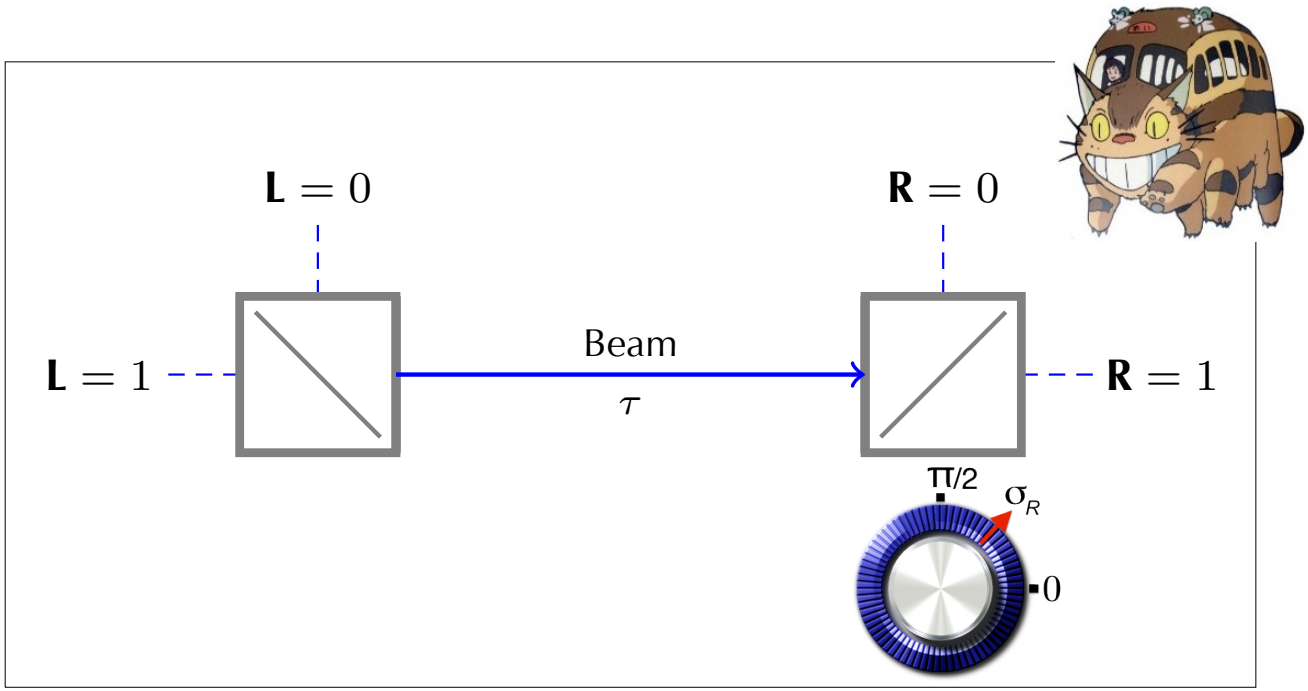

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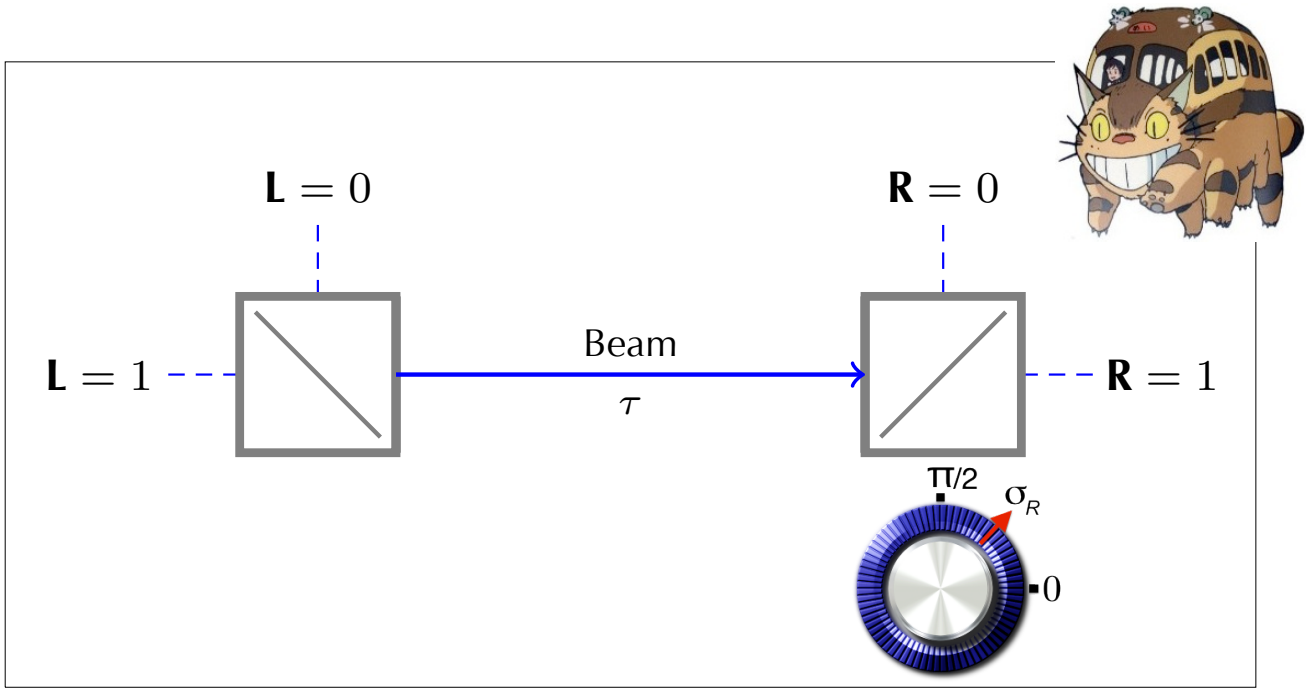

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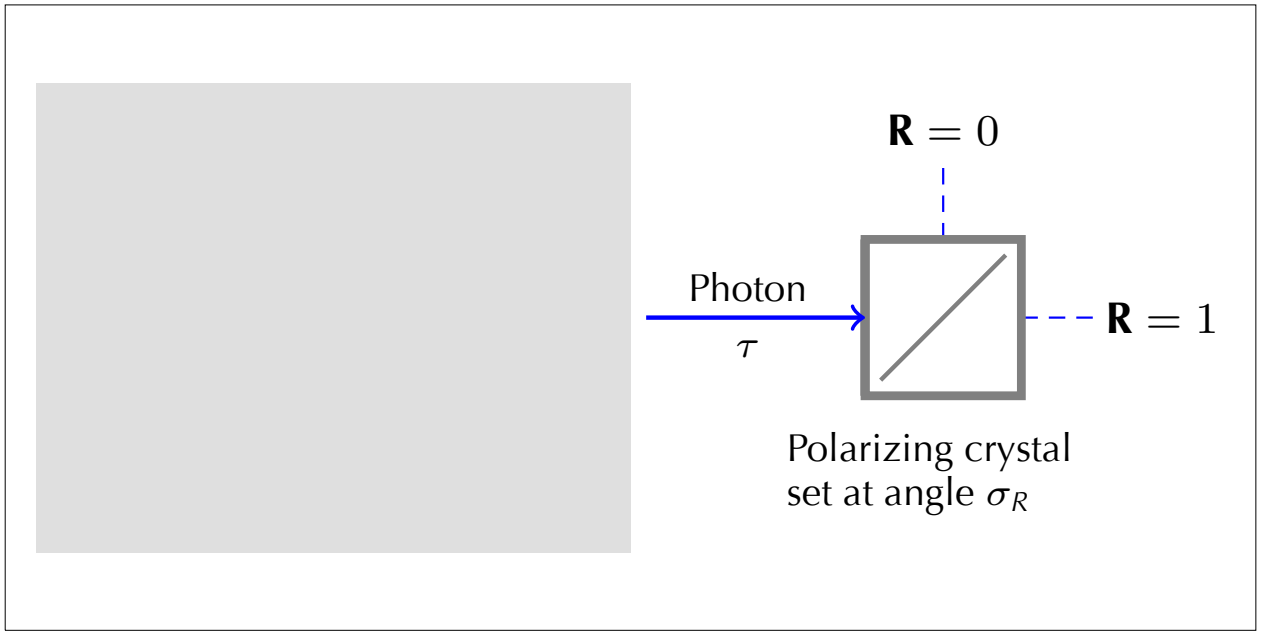

QM Malus' Law: $\text{Prob}_{\mathbf{R}=1} = \cos^2(\tau - \sigma_R)$, $\text{Prob}_{\mathbf{R}=0} = \sin^2(\tau - \sigma_R)$

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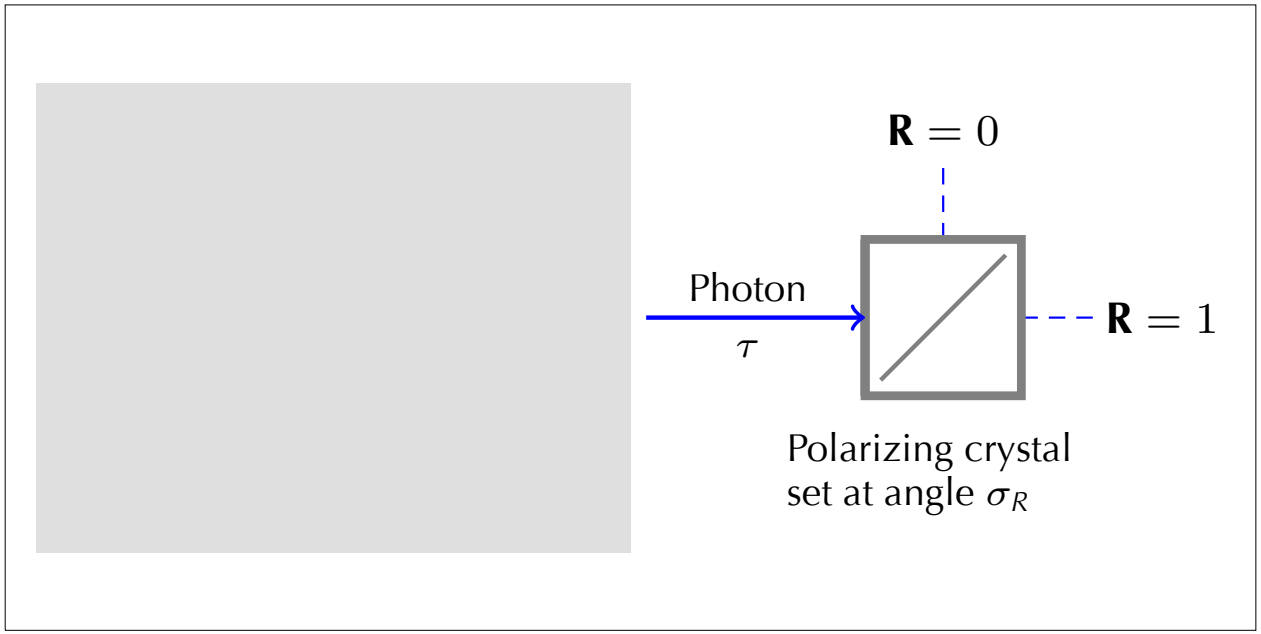

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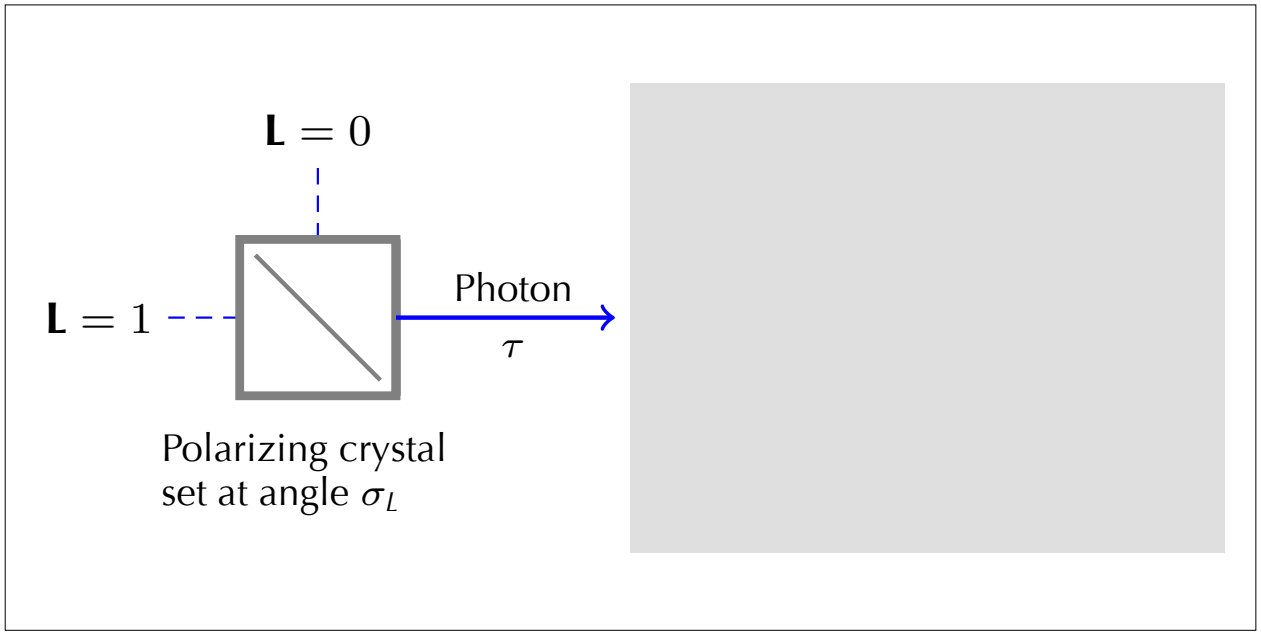

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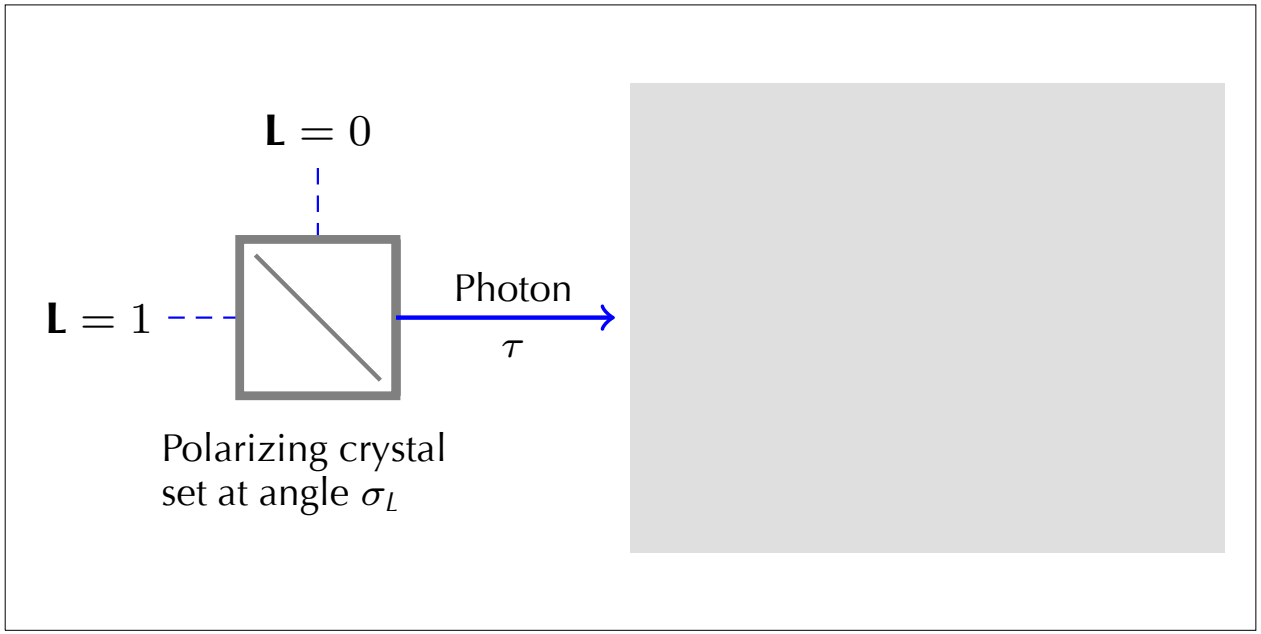

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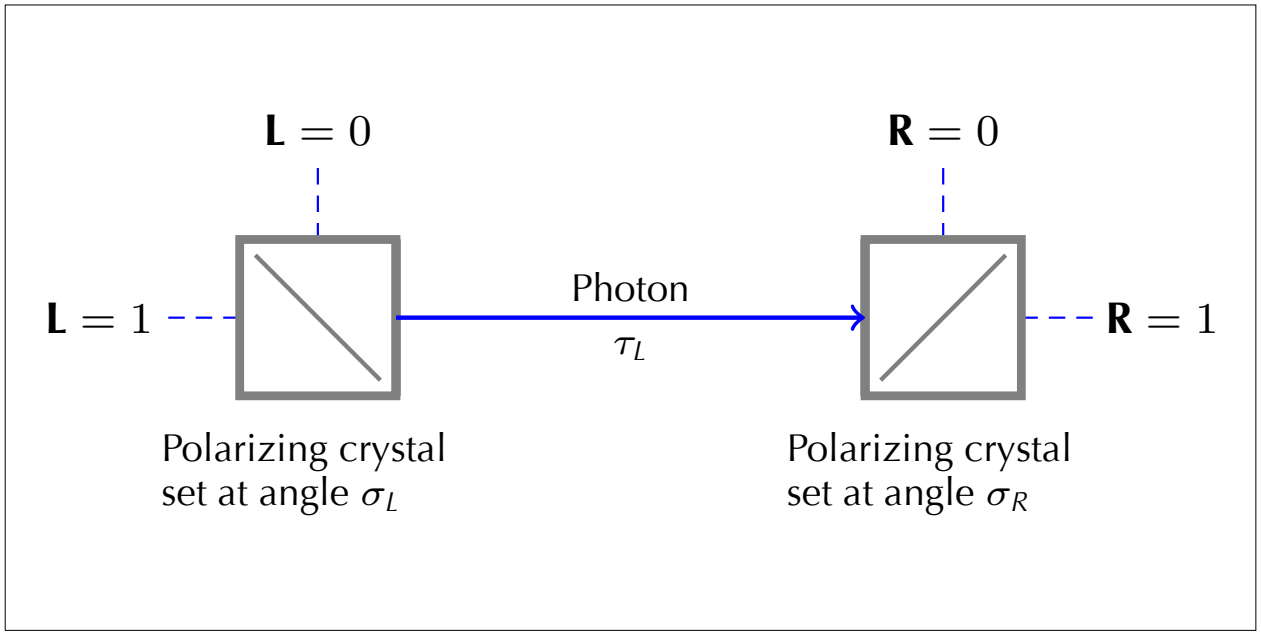
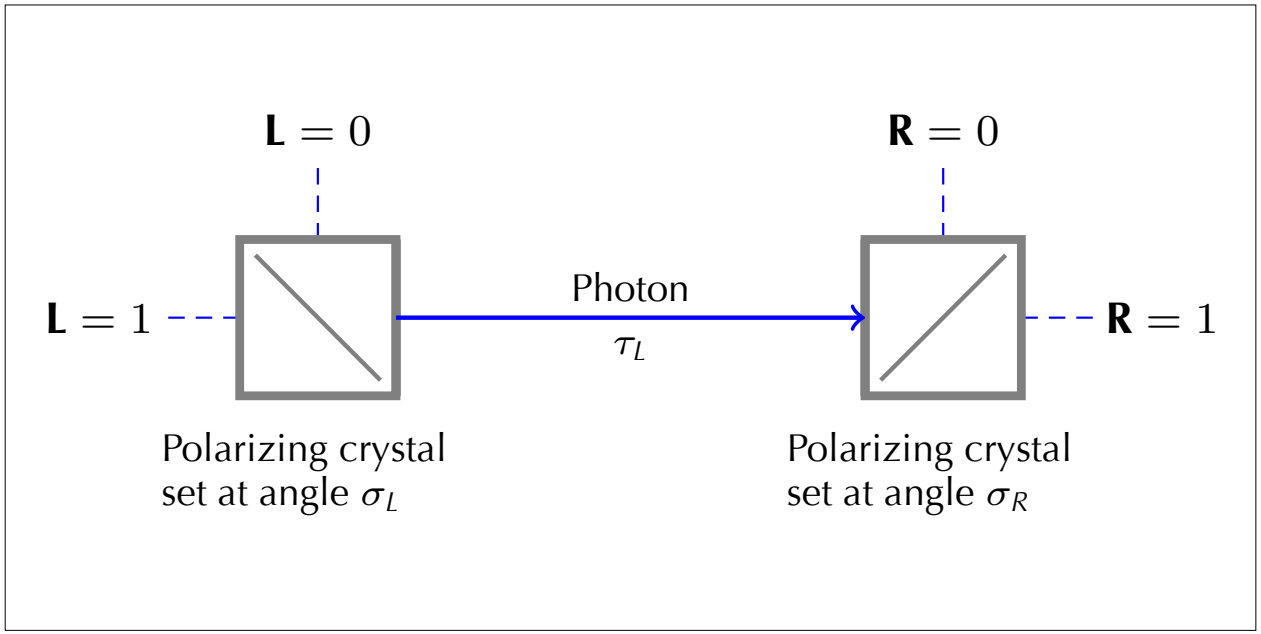
Connection and control again



1. Polarization as a local mechanism – intuitively, τ_L is just whatever 'piece of reality' ('beable') connects **changes** on the left to **changes** on the right. (Let **Realism** be the assumption that here is some such beable.)
2. What we can wiggle?

Connection and control again



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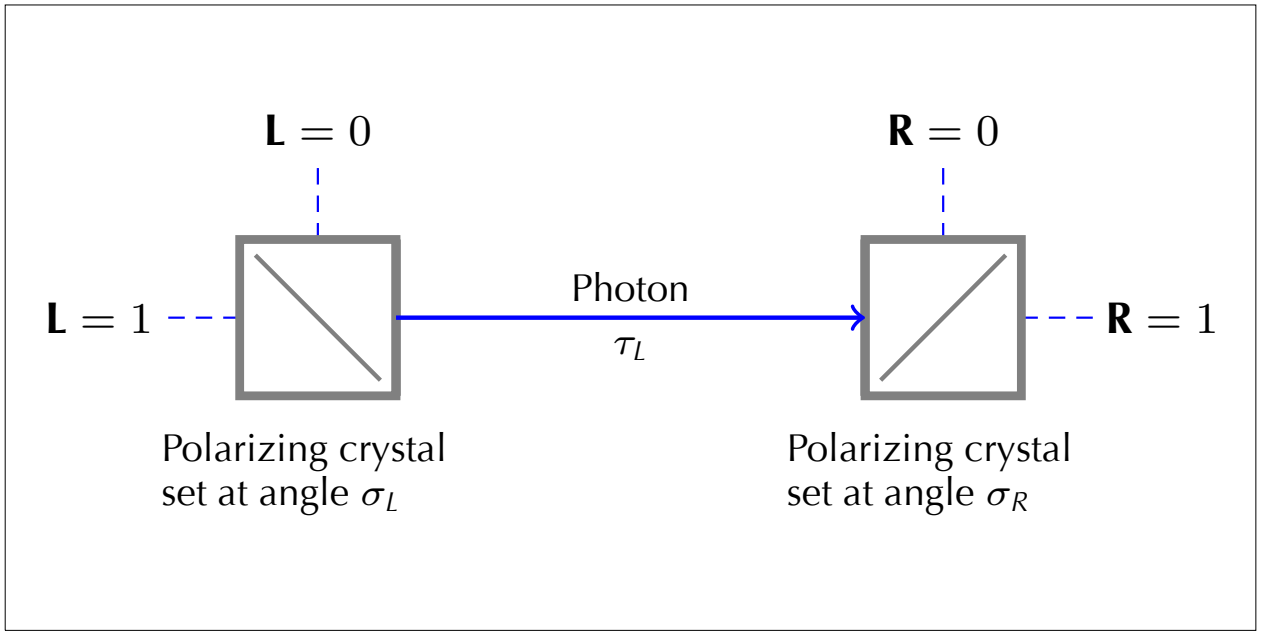

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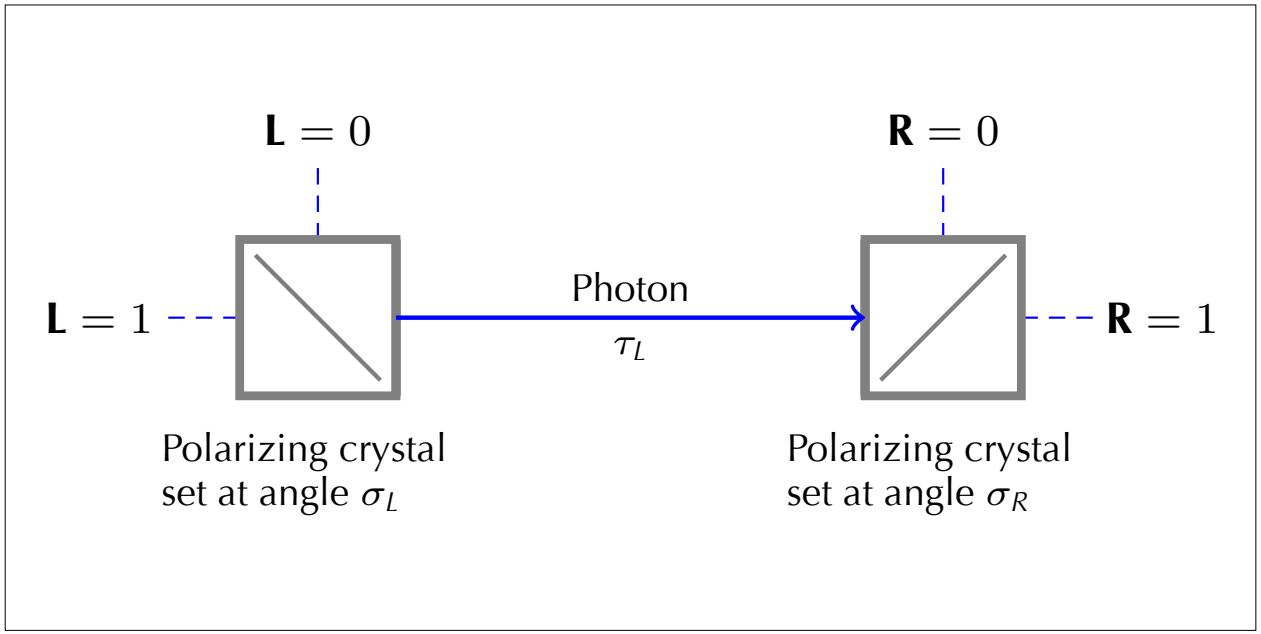

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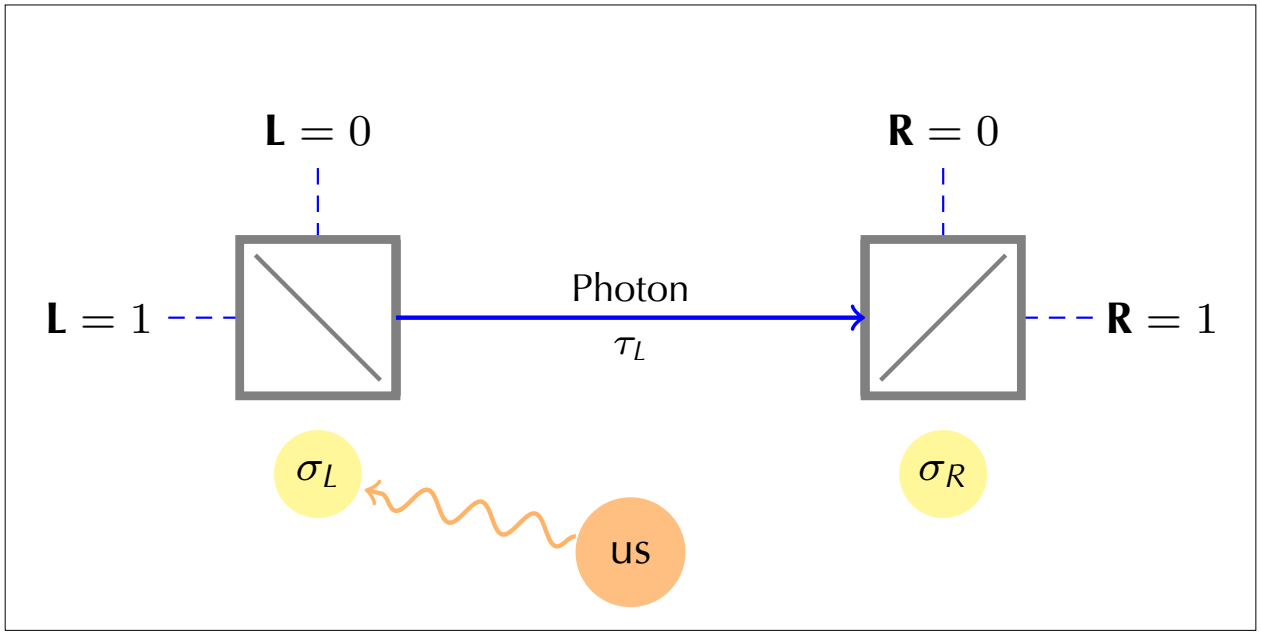

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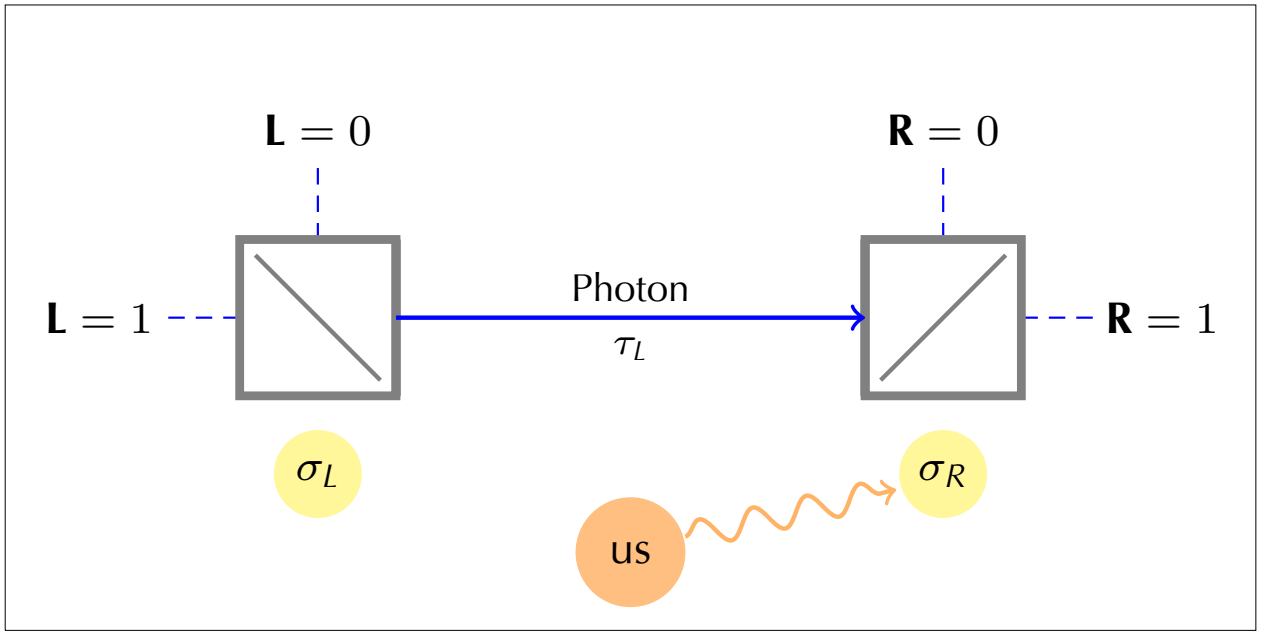

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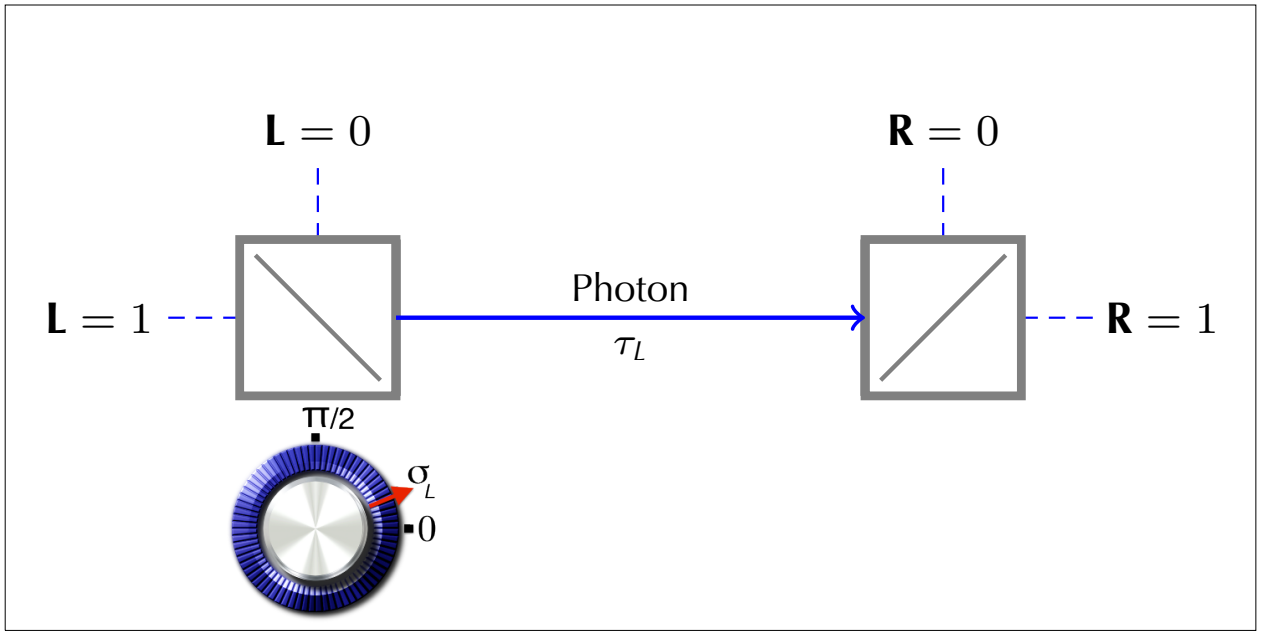

- Again, suppose we control the left polarizer, σ_L, but **not** the input photons – the Demon of the Left controls those. Can we control τ_L?
- **Yes** … so long as the Demon **has to put the photon on one channel or other** (the **Discreteness** assumption). In this case, $\tau_L = \sigma_L$ or $\tau_L = \sigma_L + \pi/2$. So we can't fix τ_L completely, but we can restrict it to just **two** possibilities. ('Price control'?)

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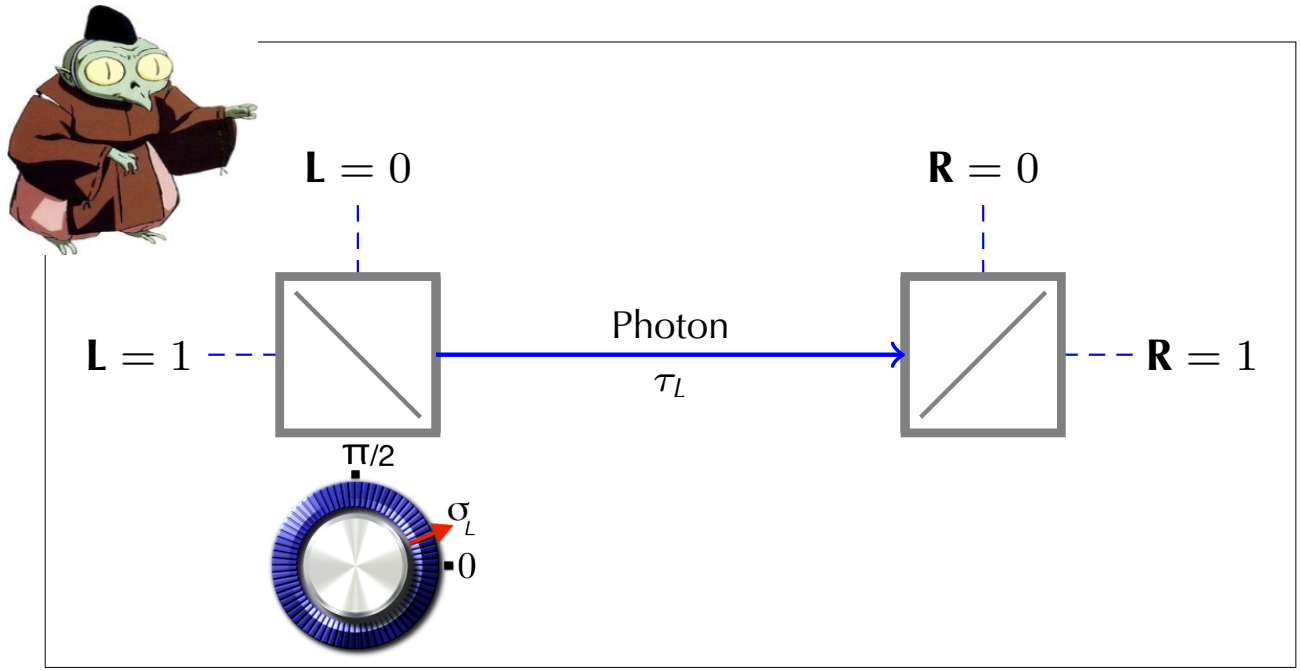

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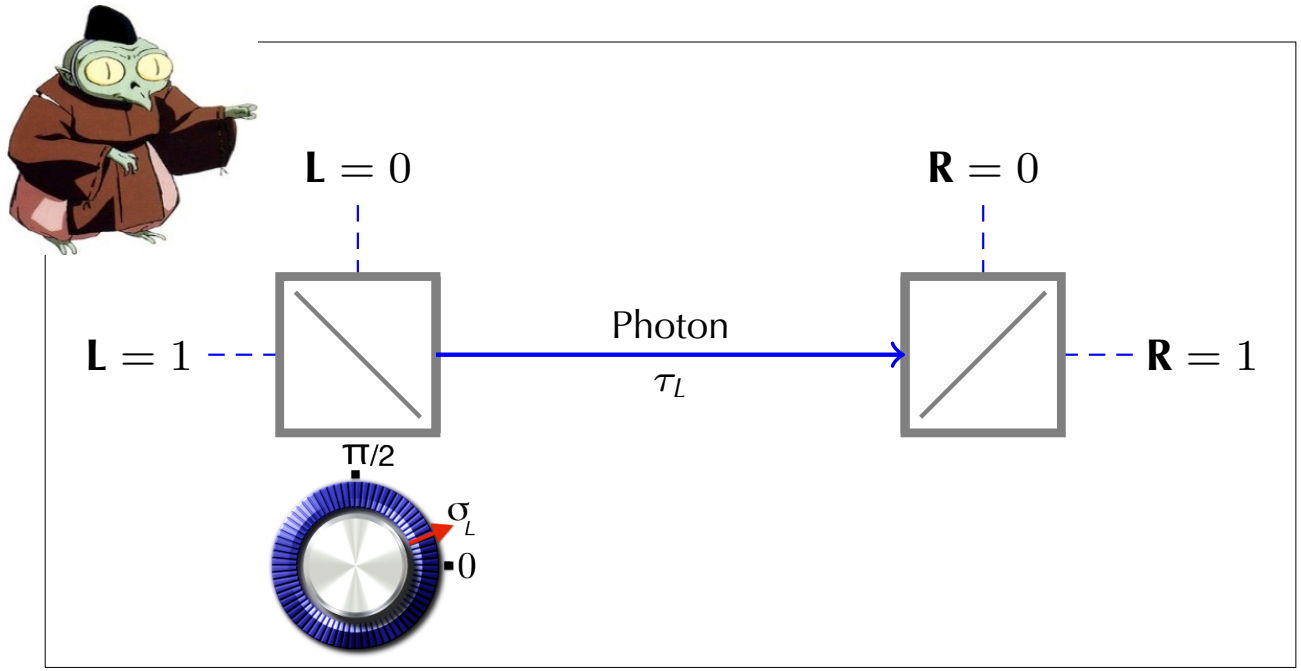

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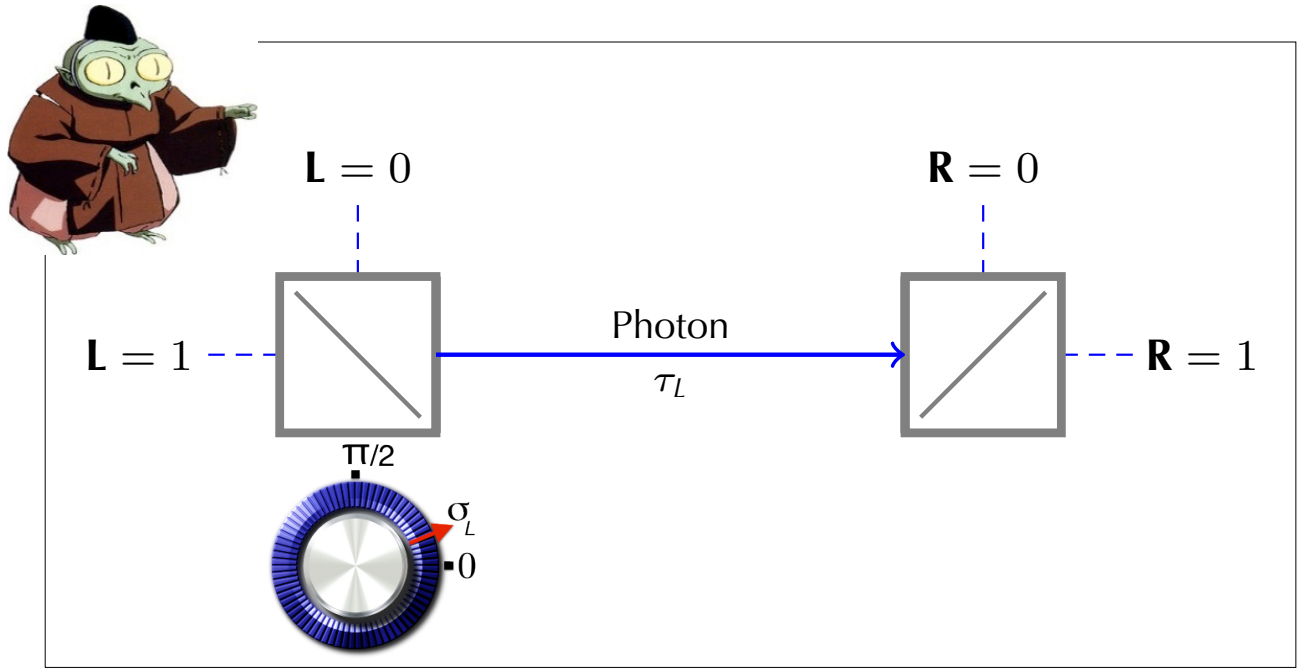

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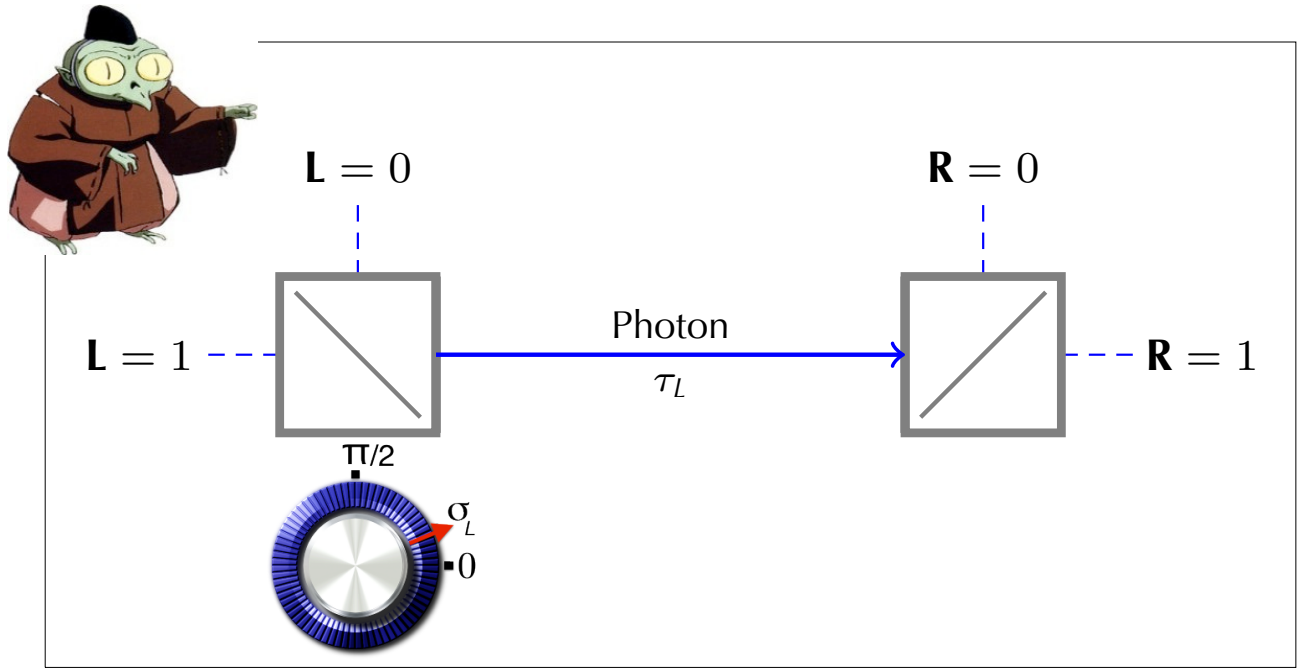

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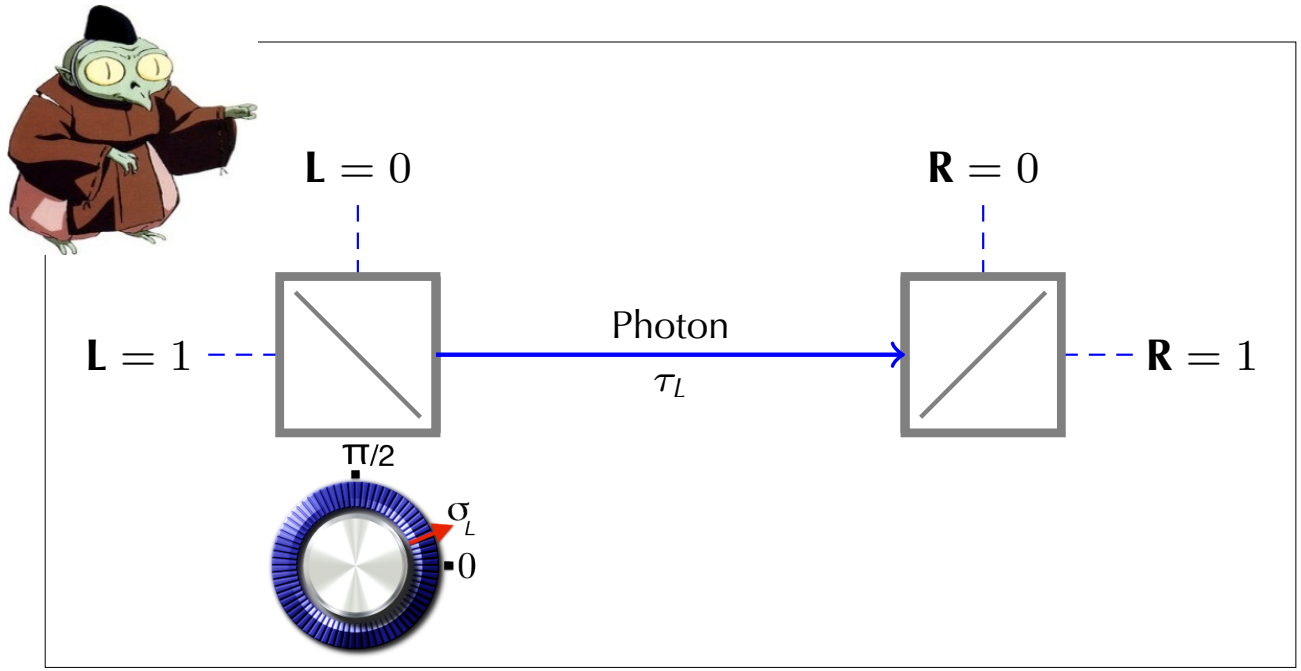

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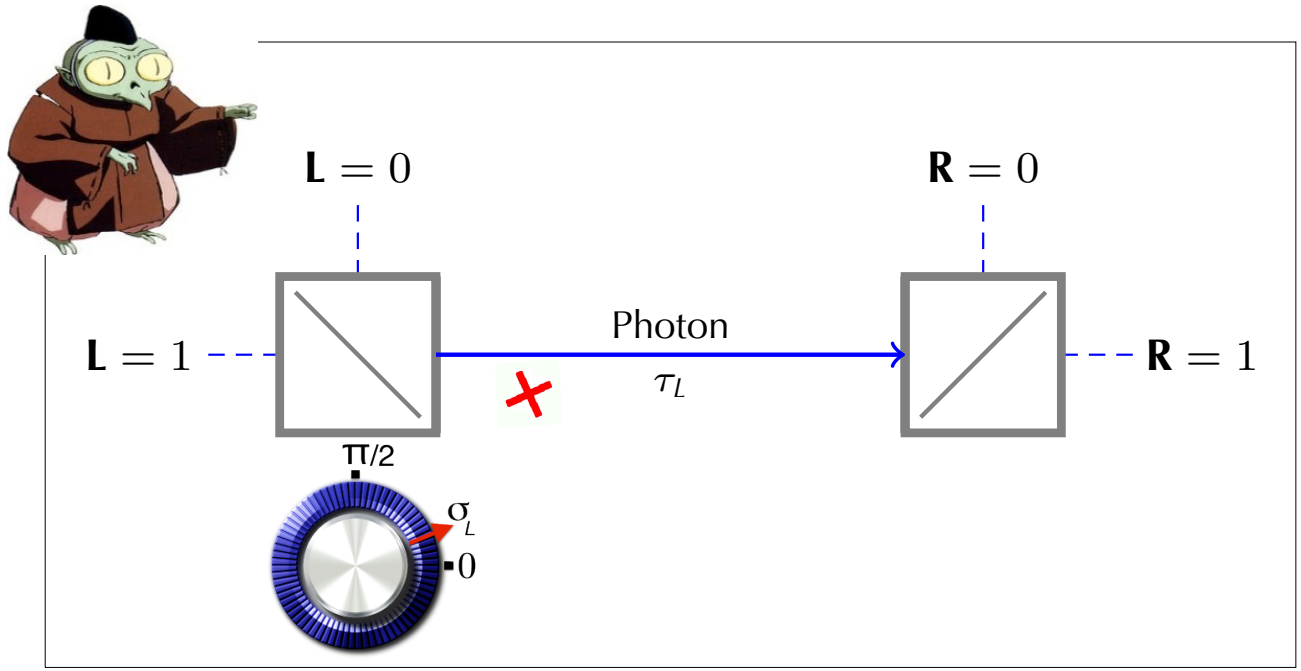

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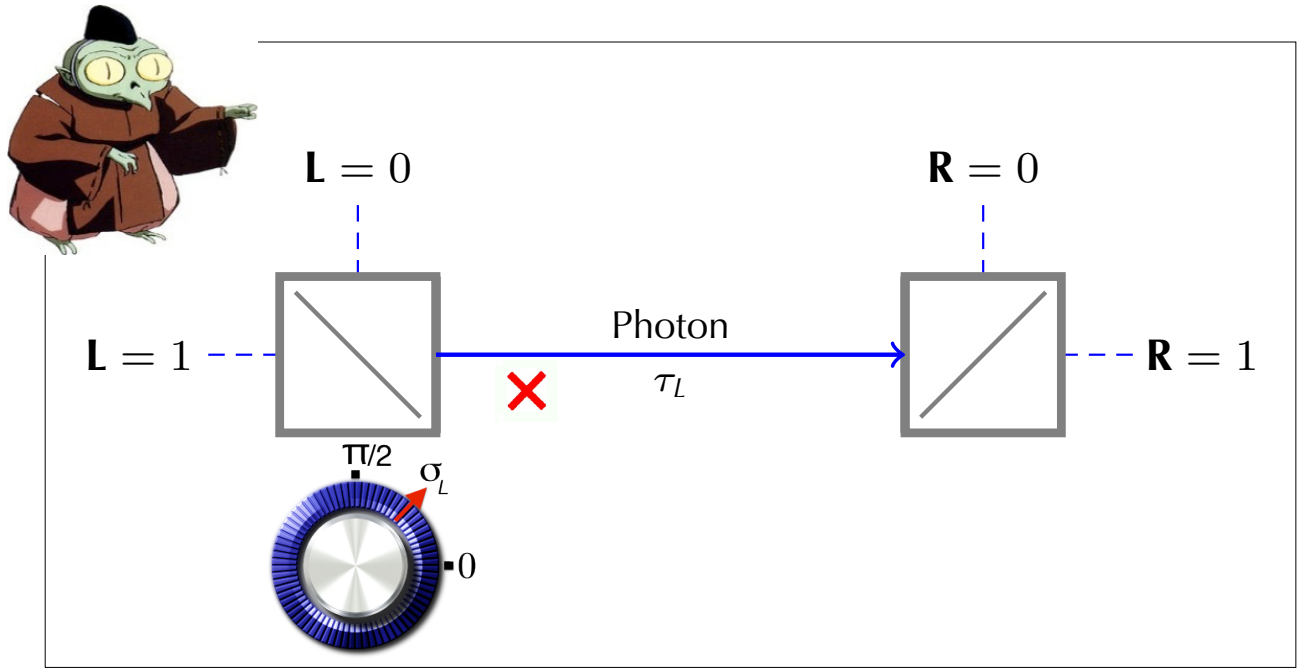

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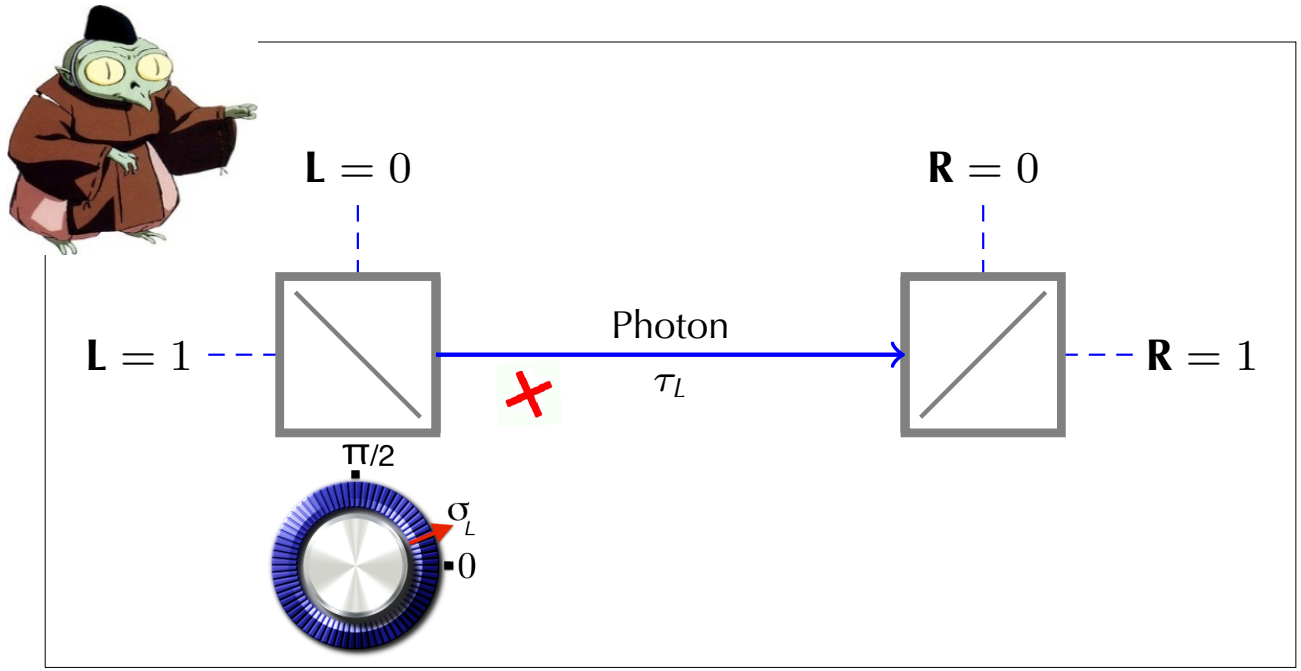

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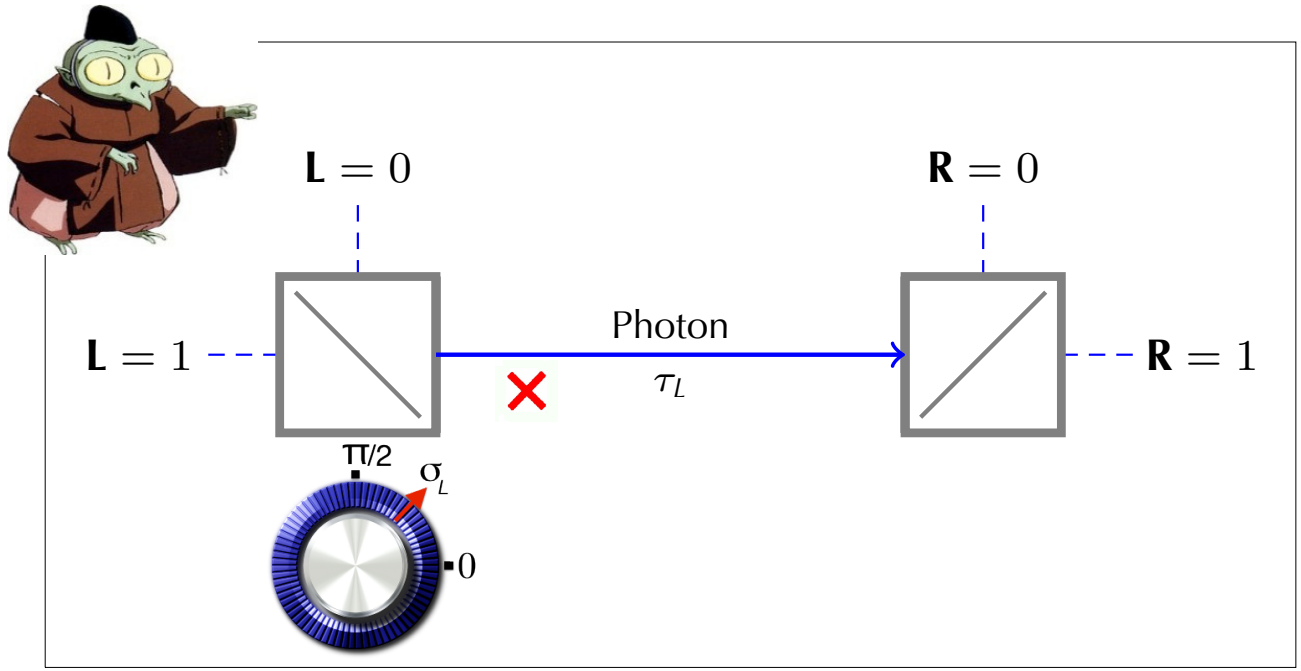

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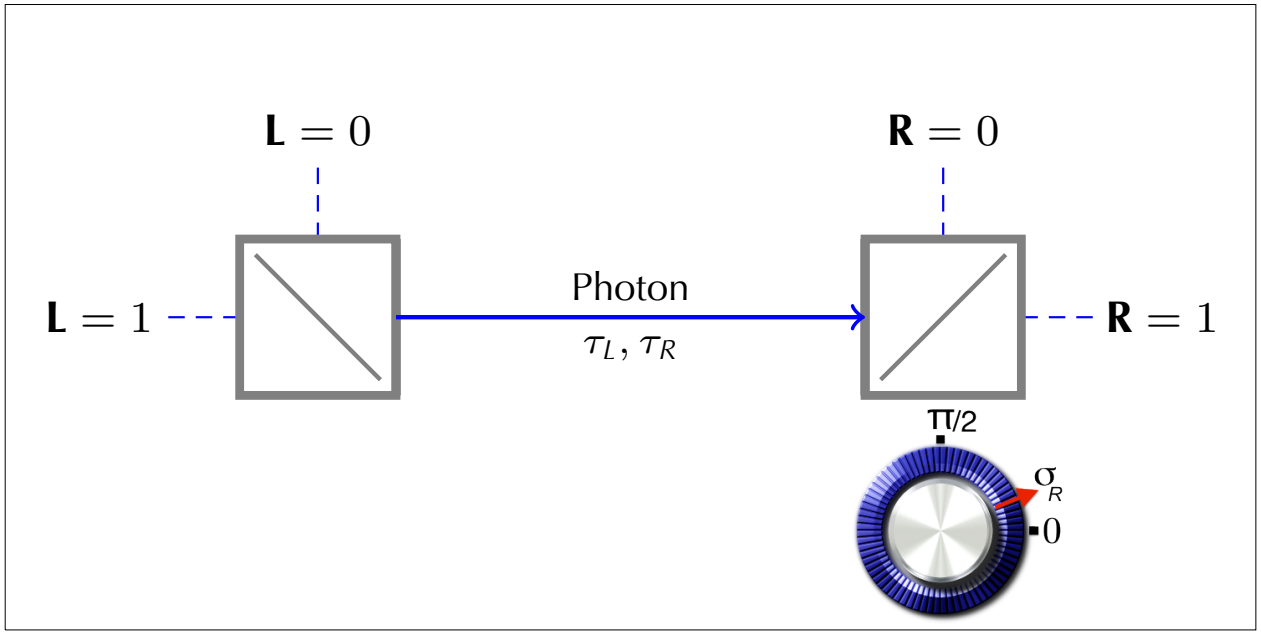

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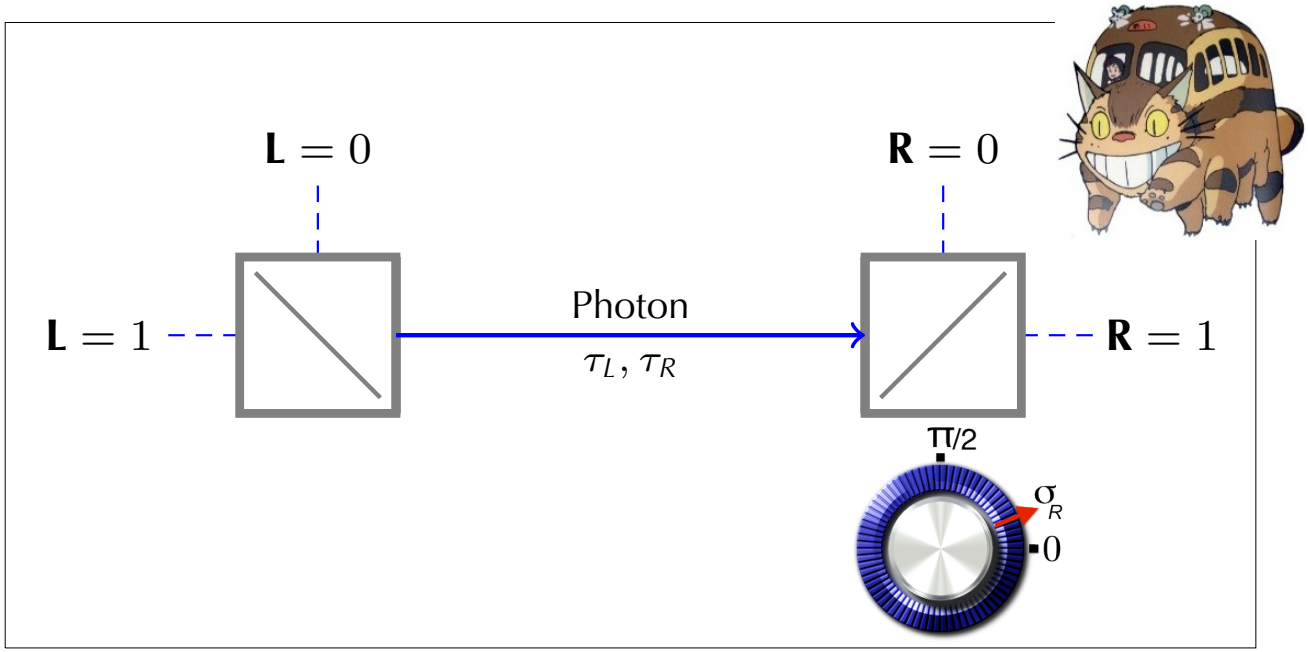

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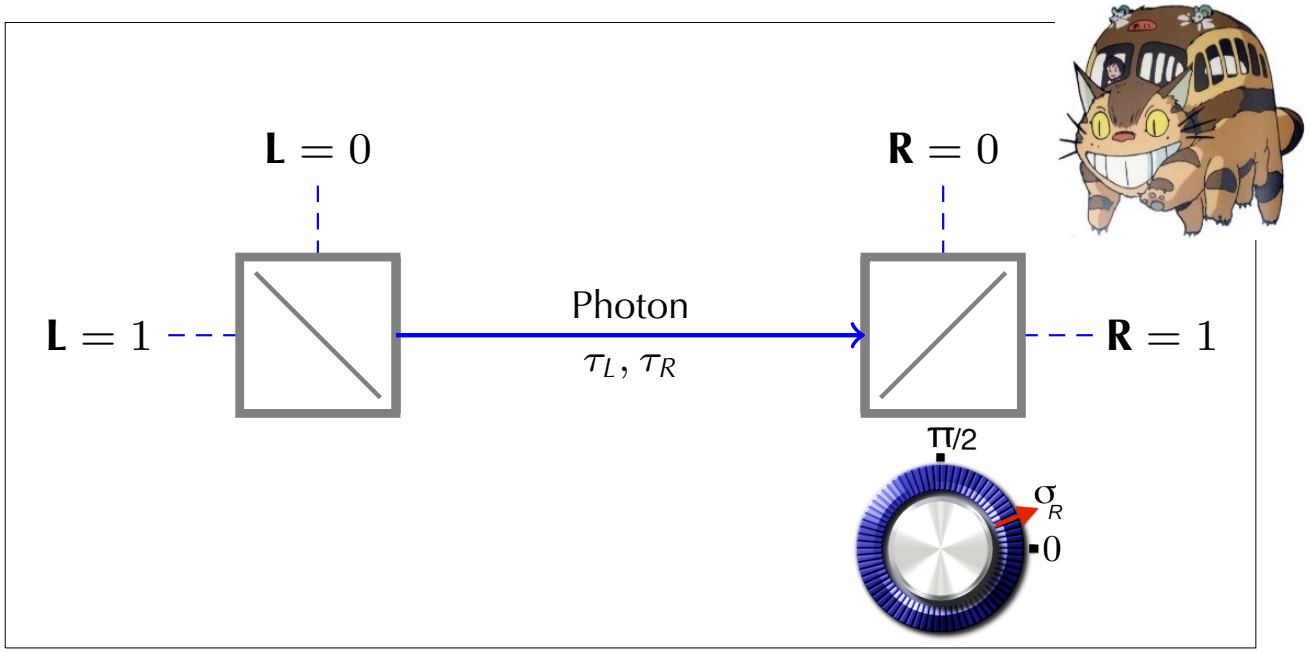

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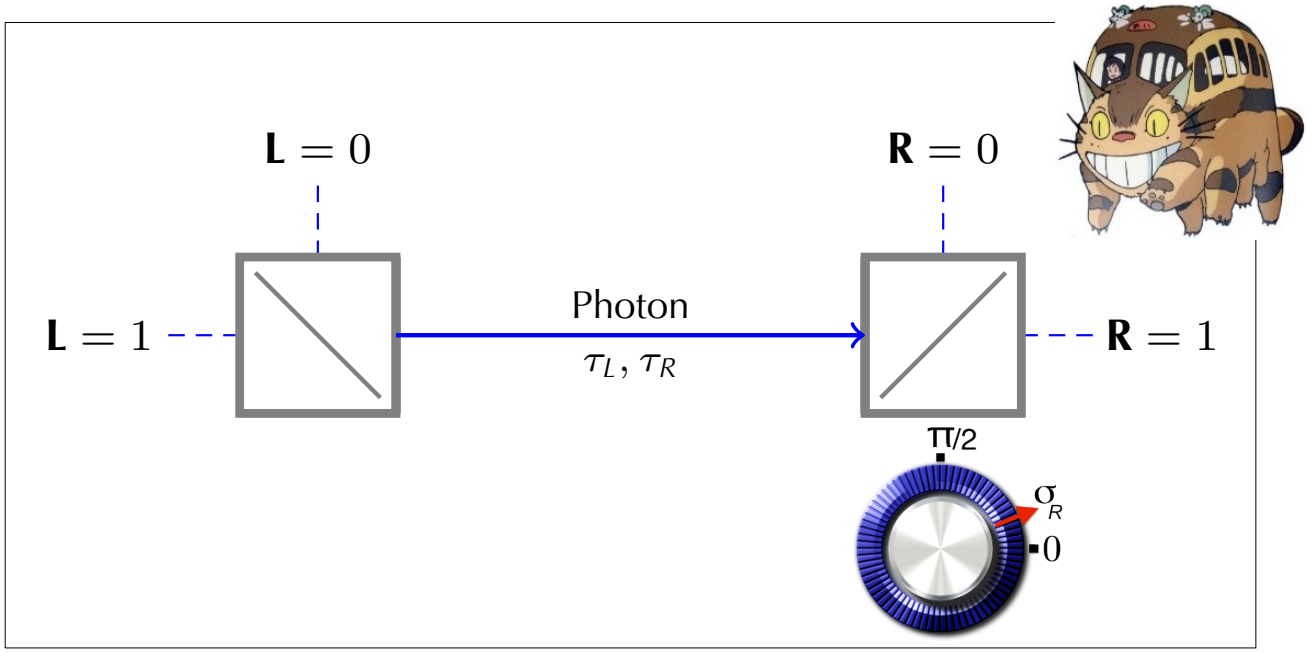

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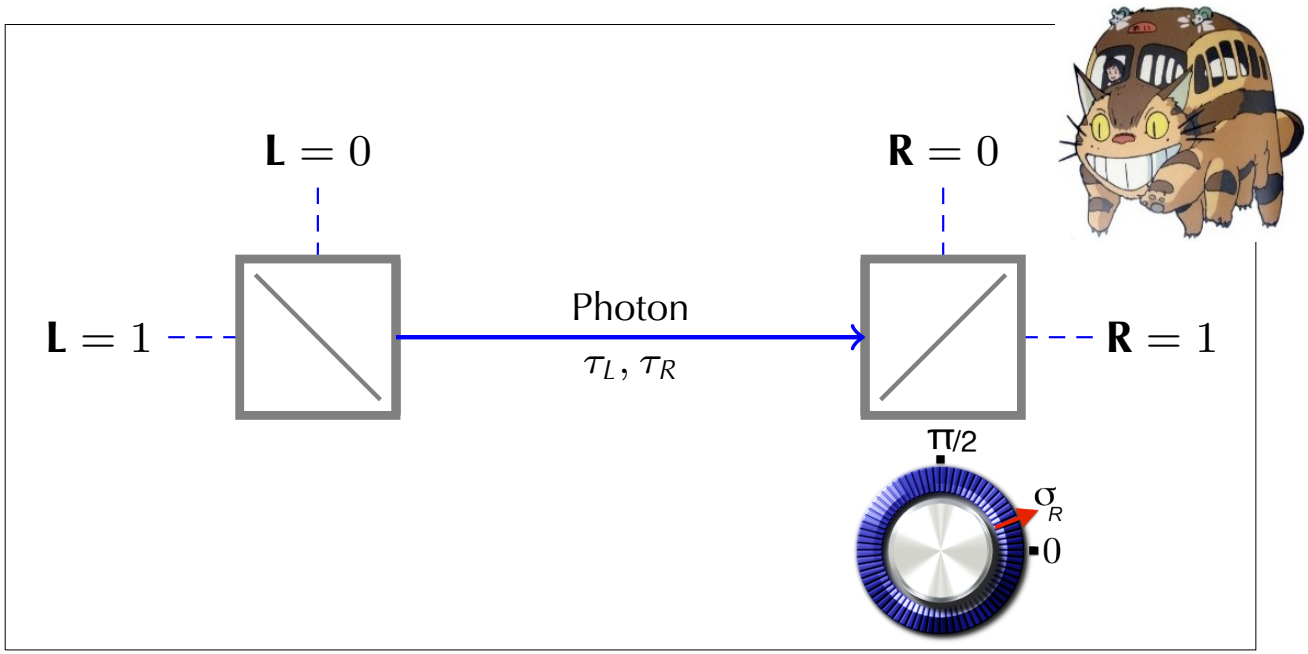

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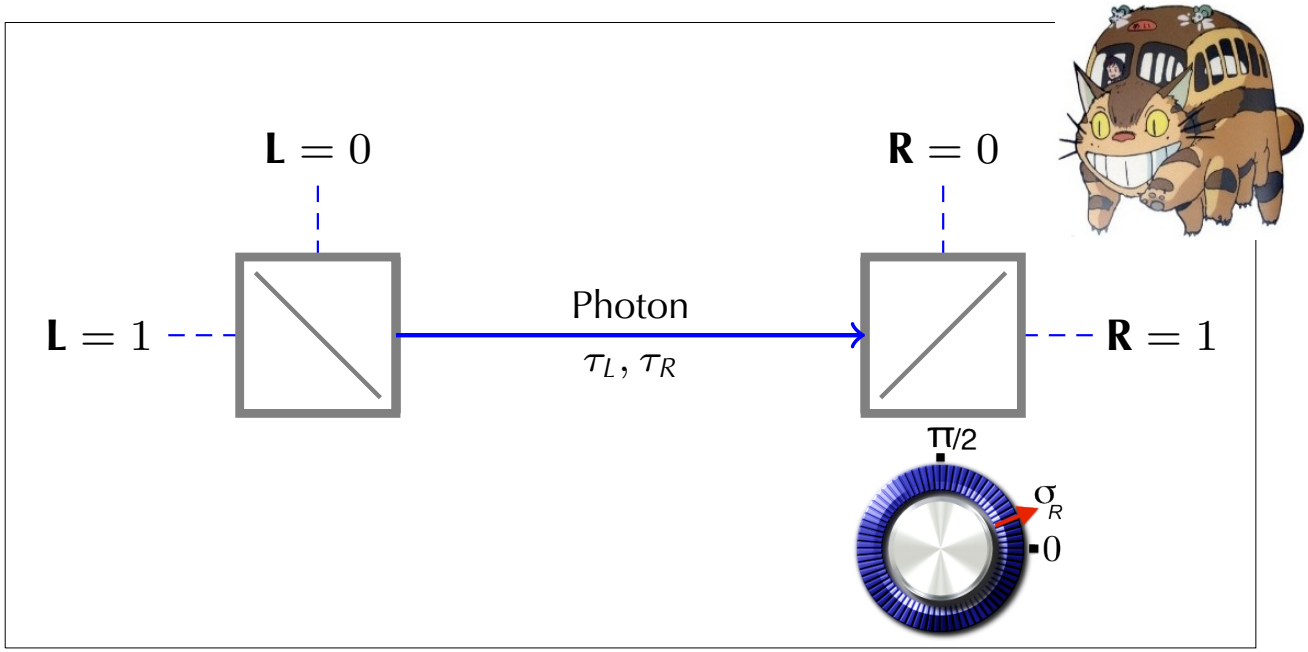

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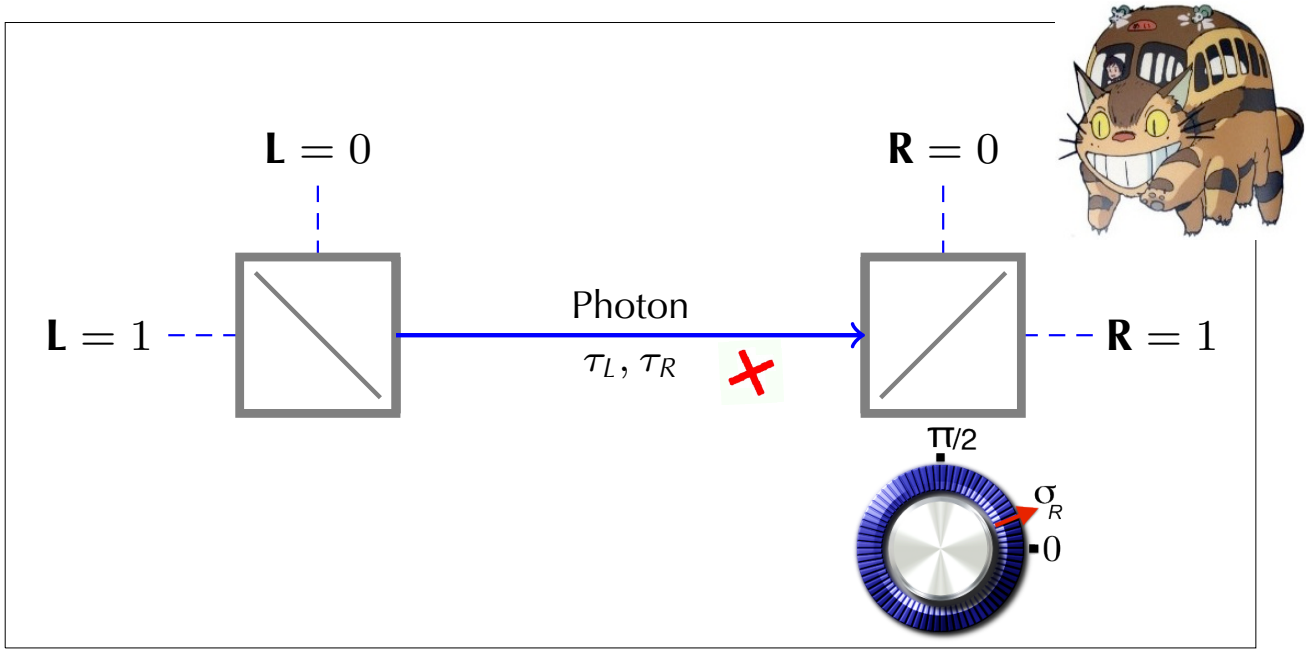

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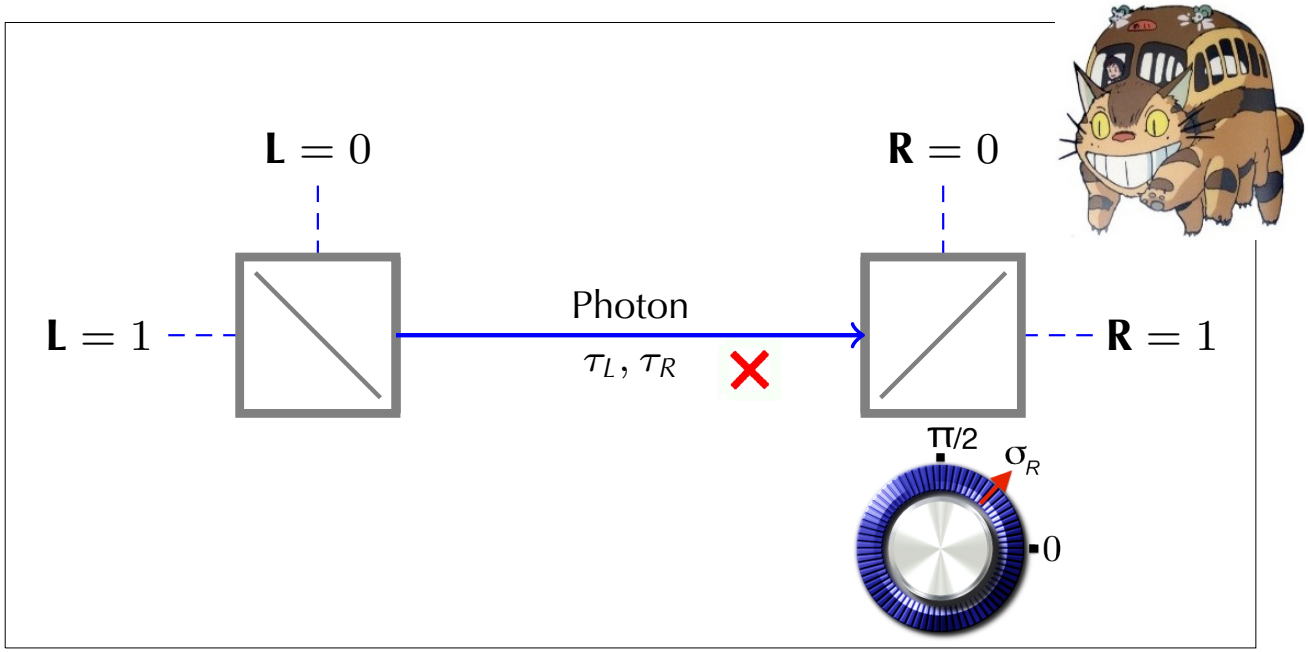

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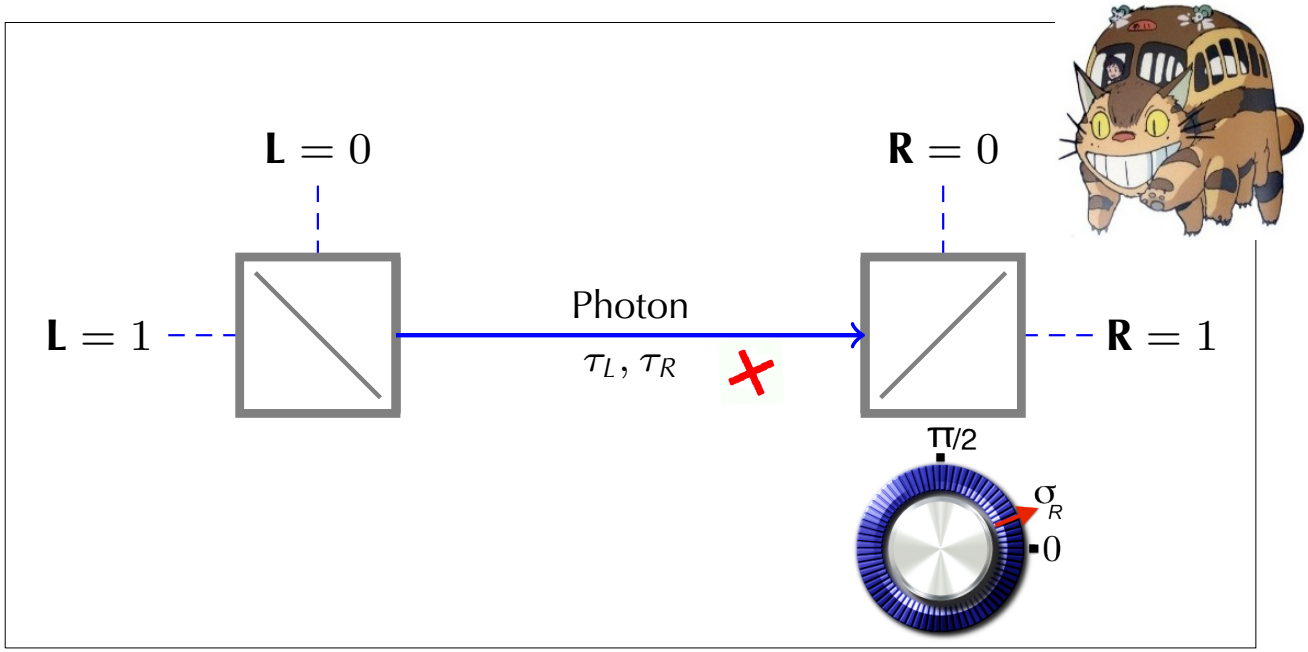

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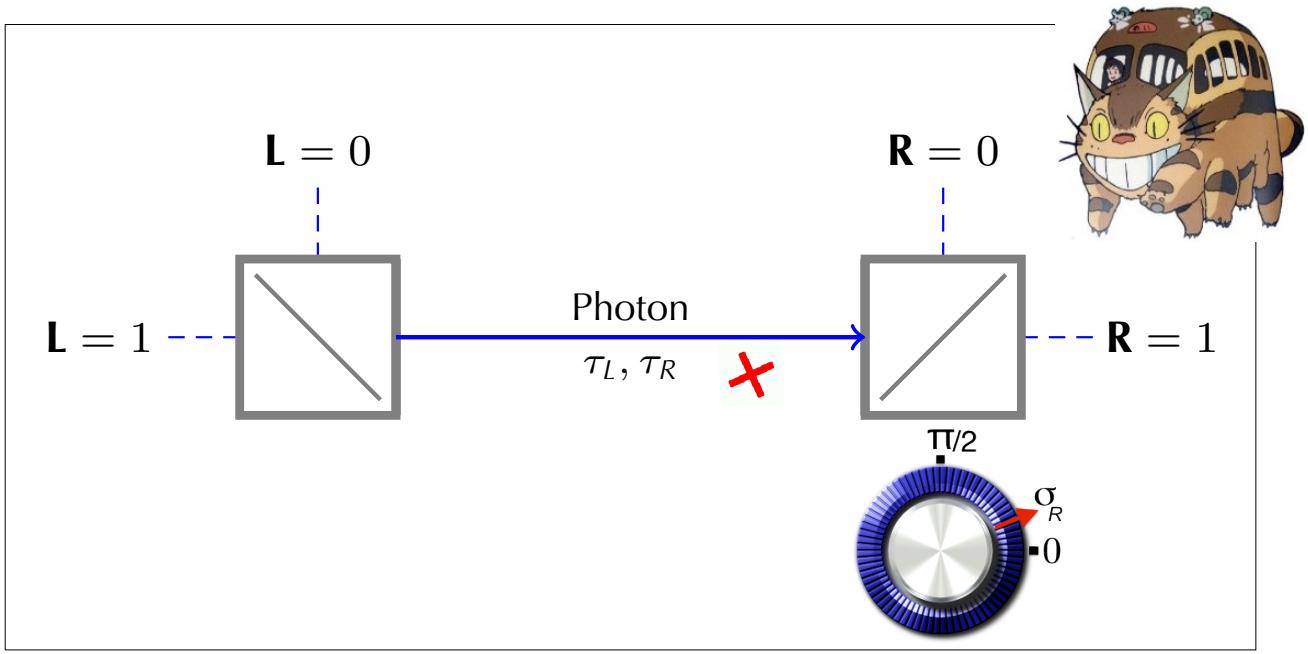

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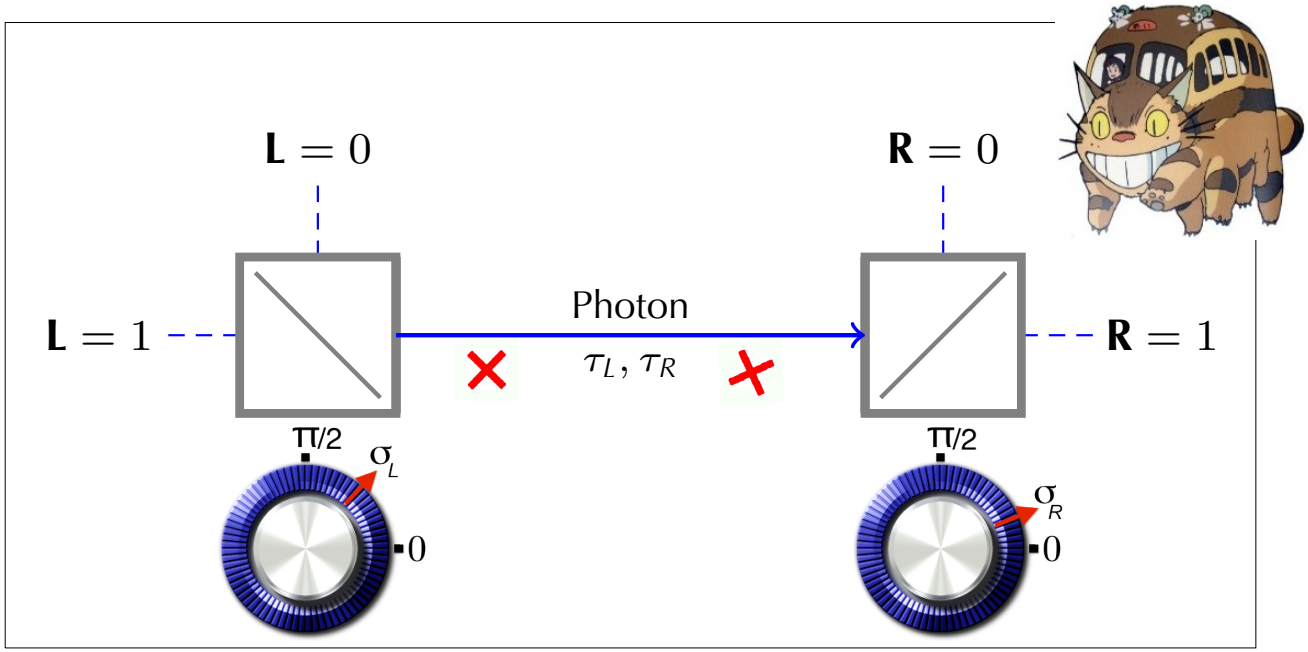

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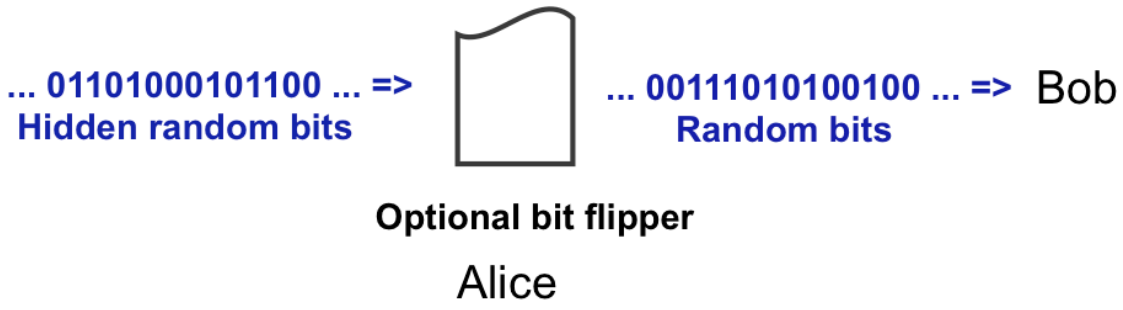

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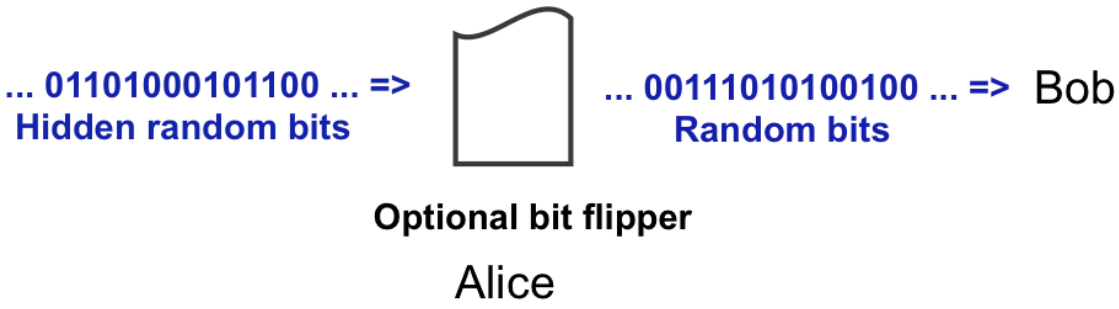

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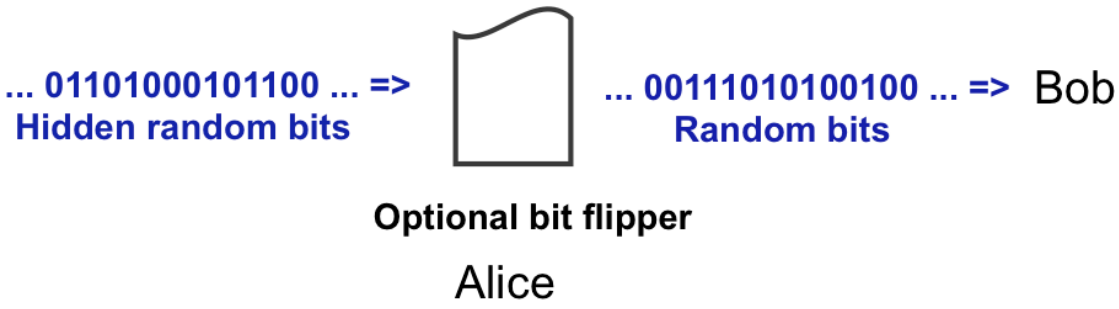

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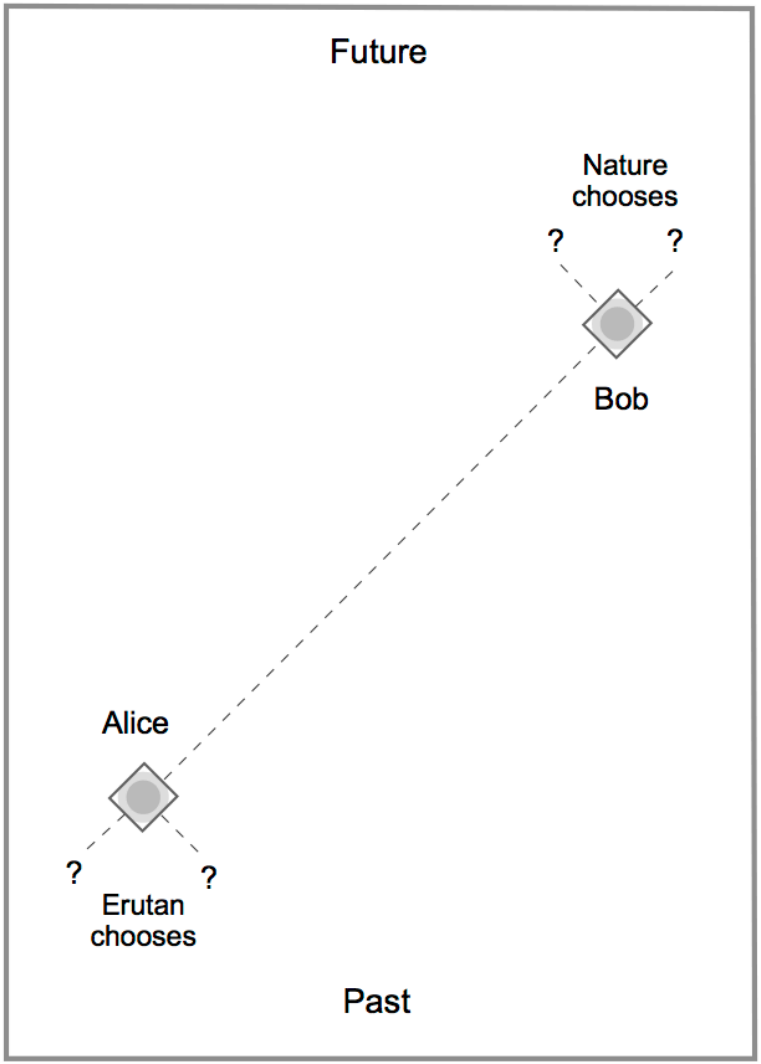

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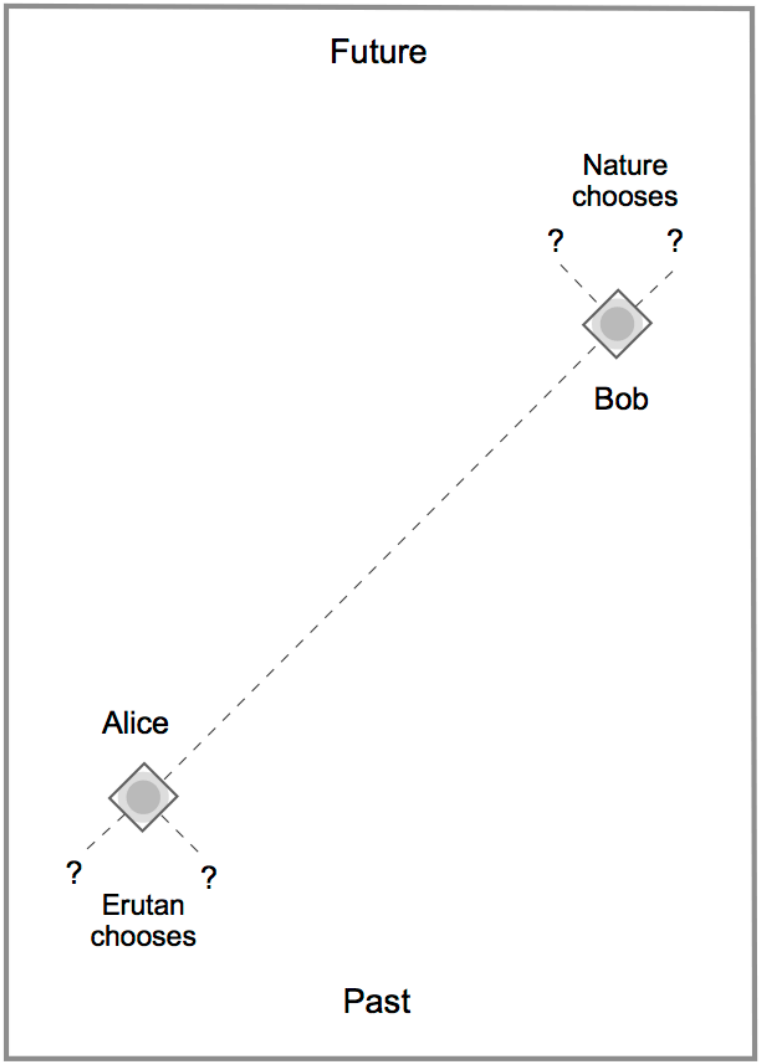

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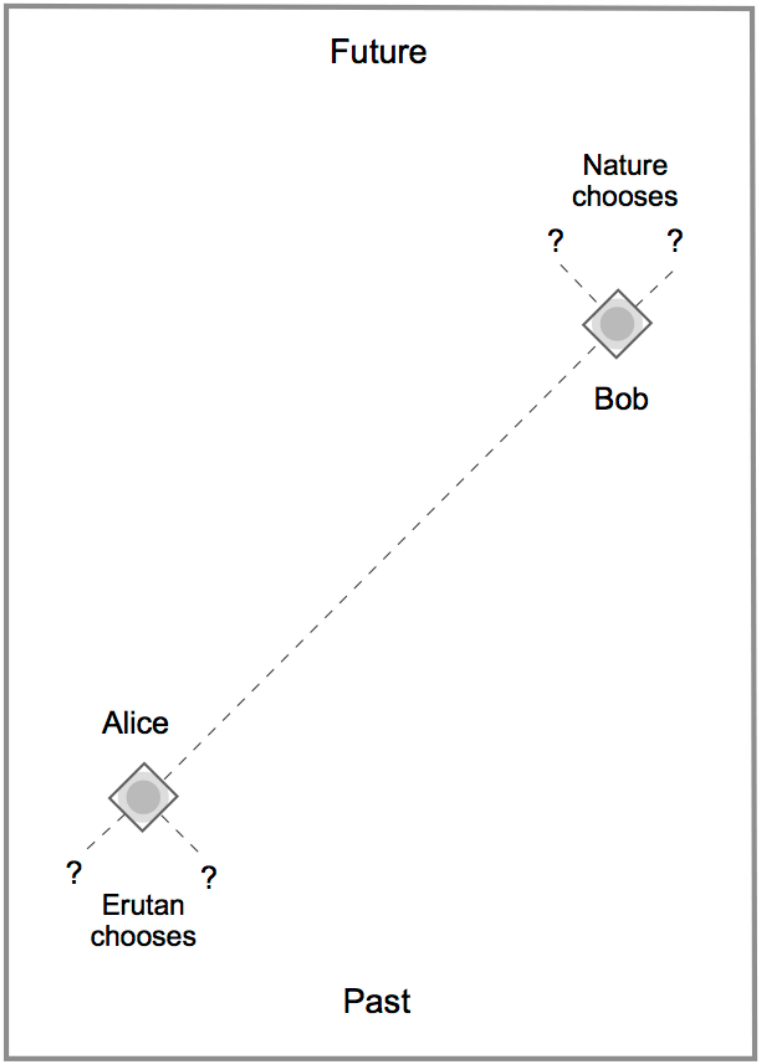

Causality without signalling in QM

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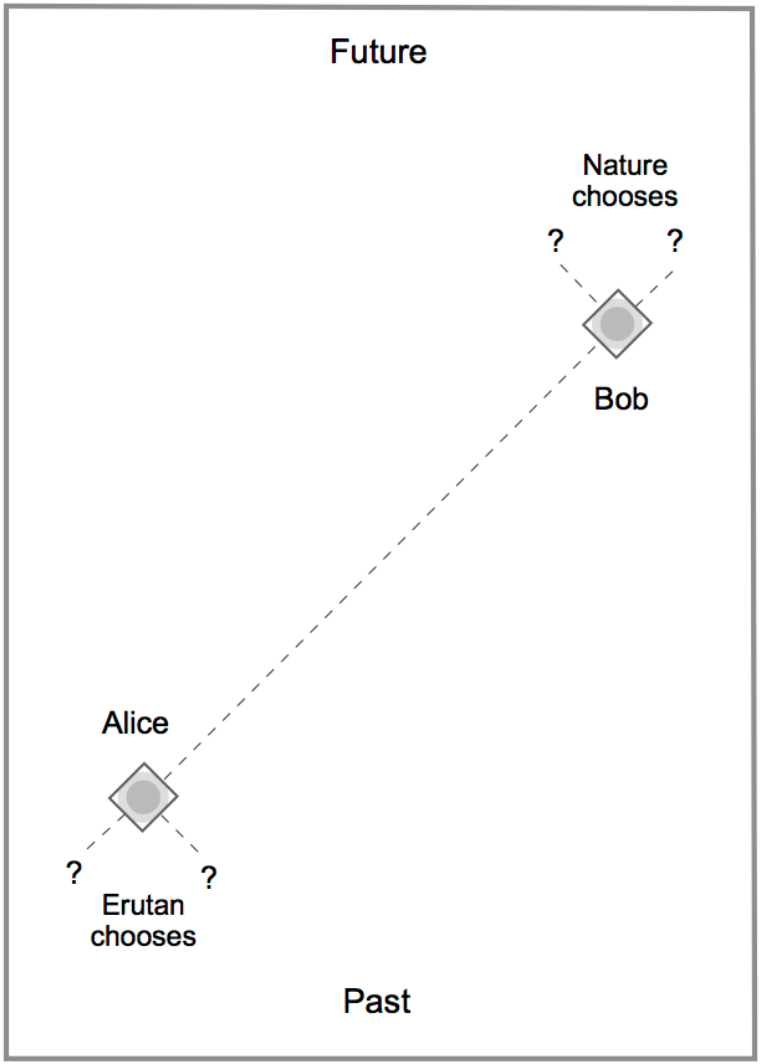

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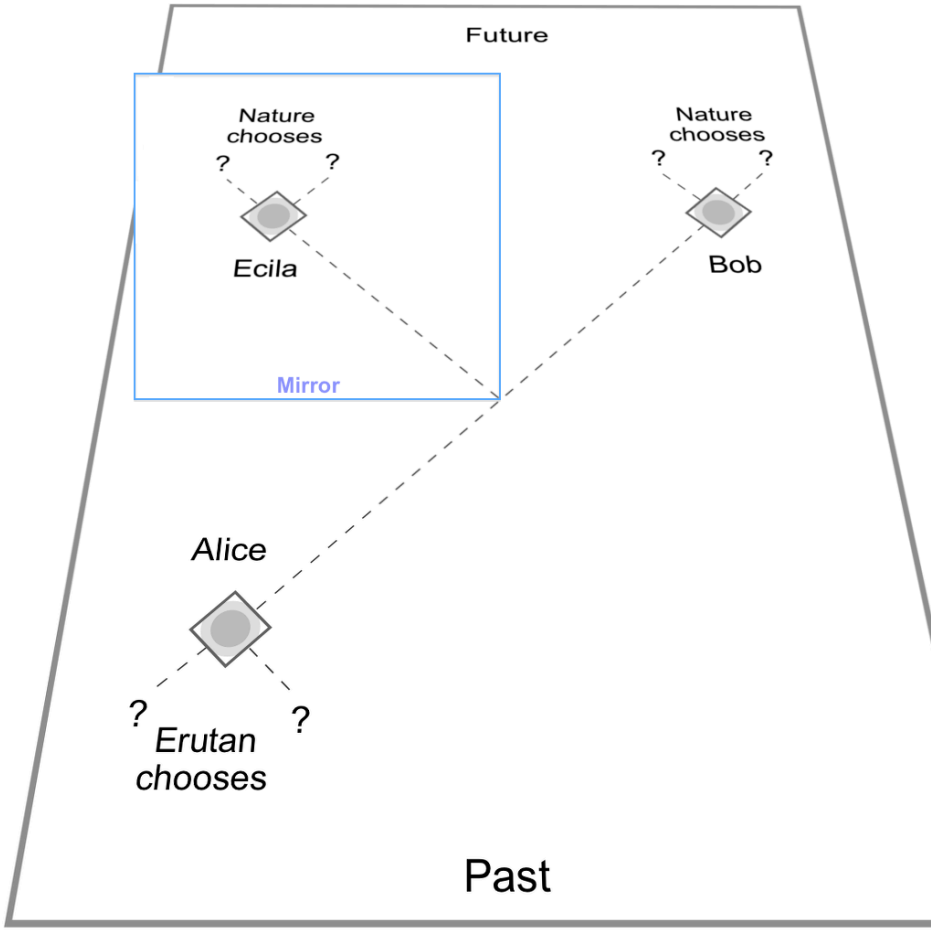

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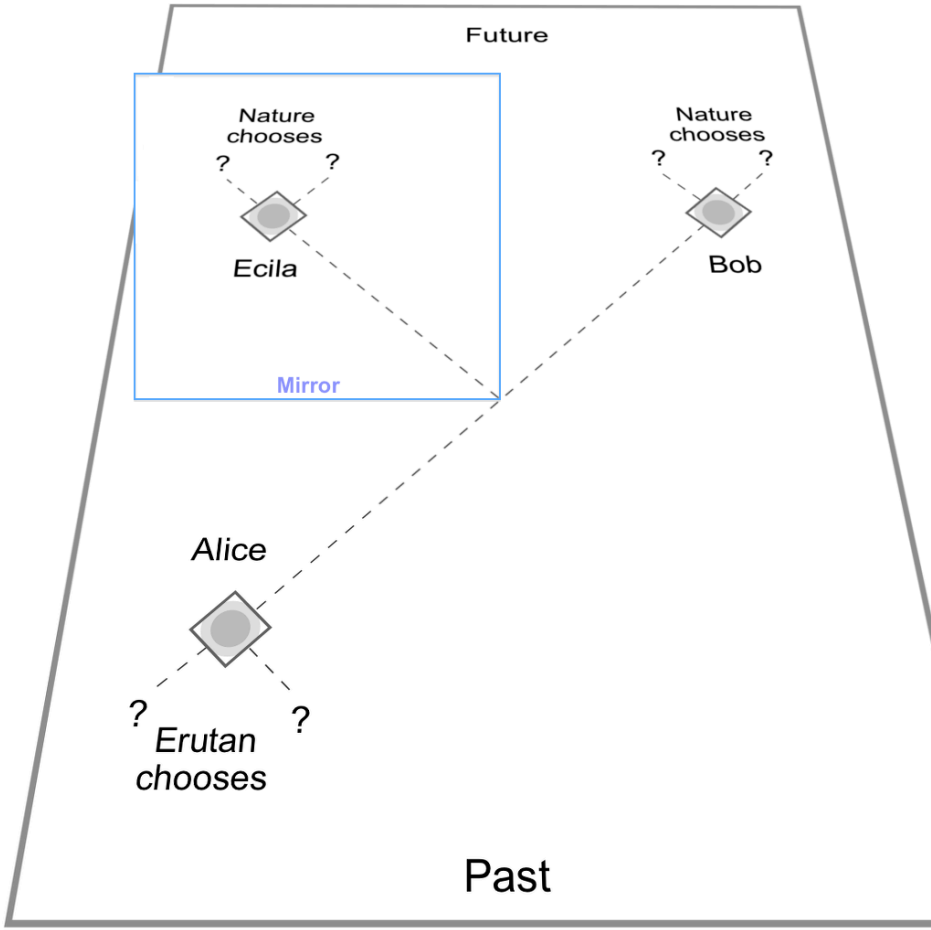

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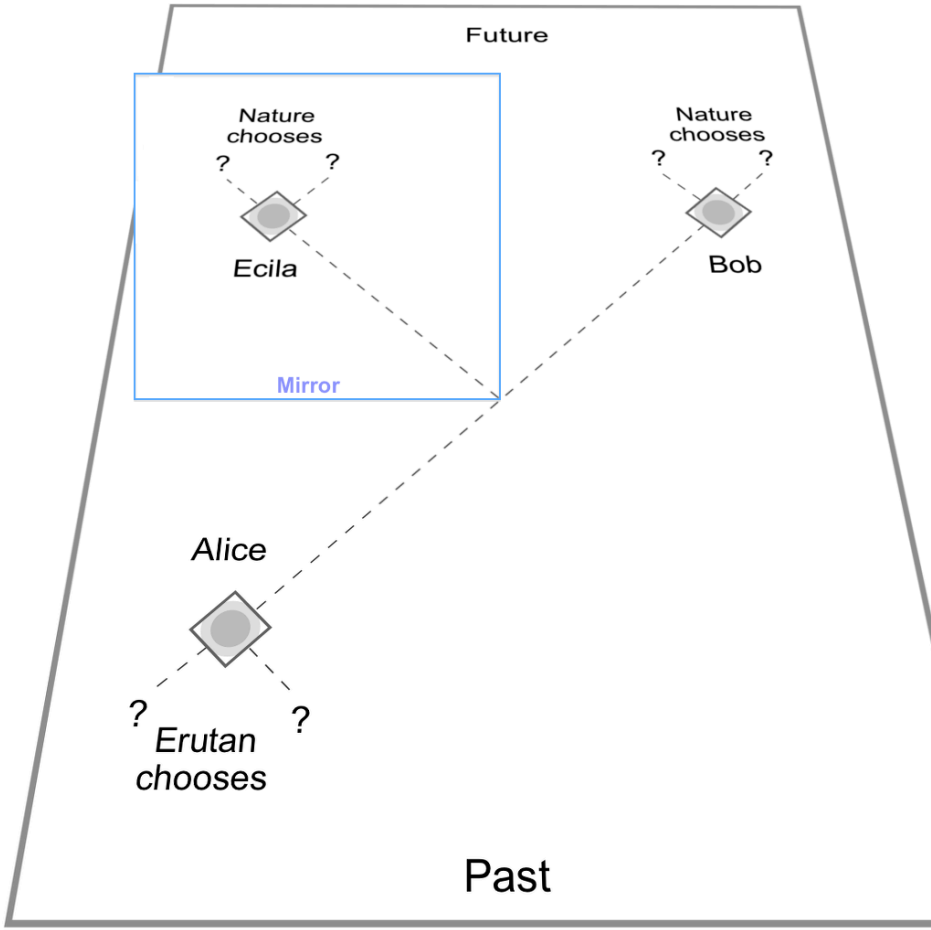

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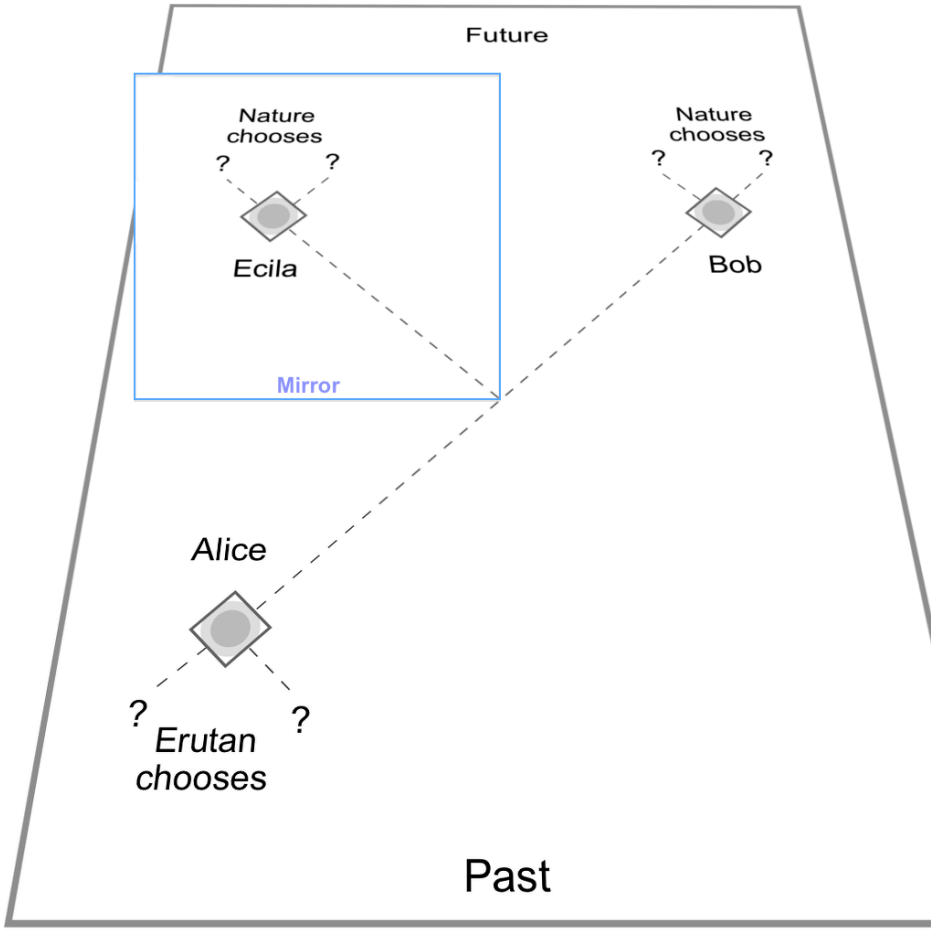

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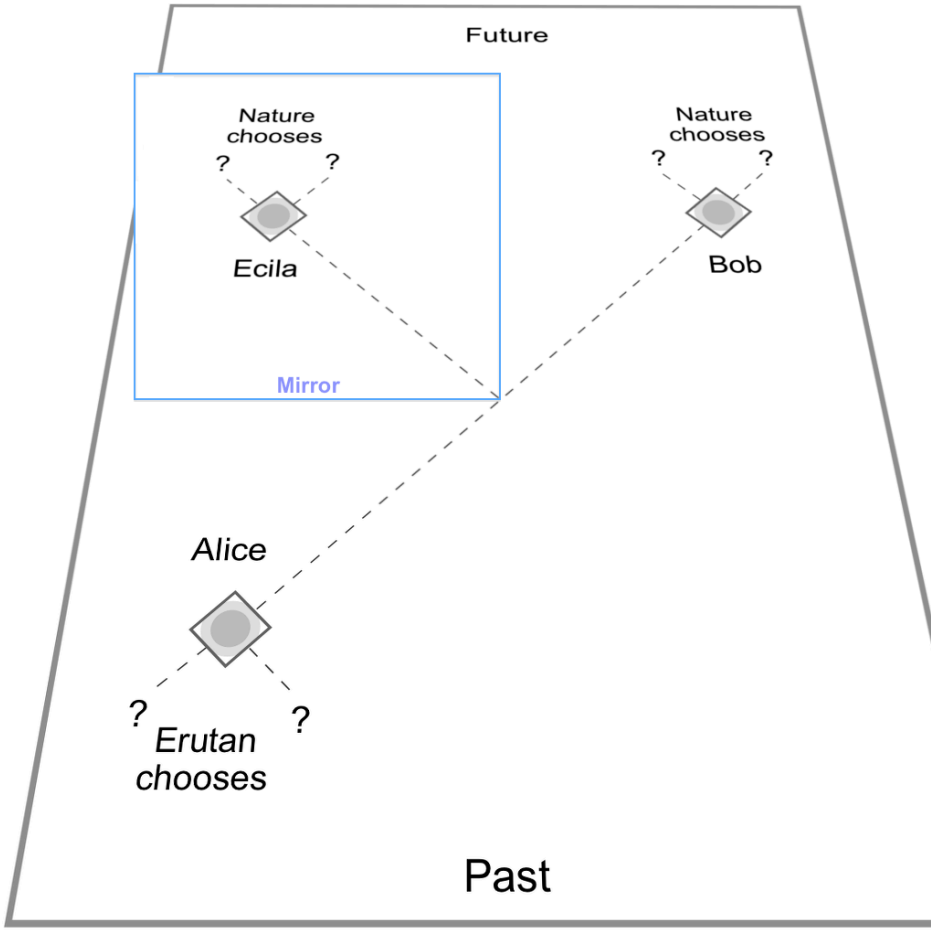

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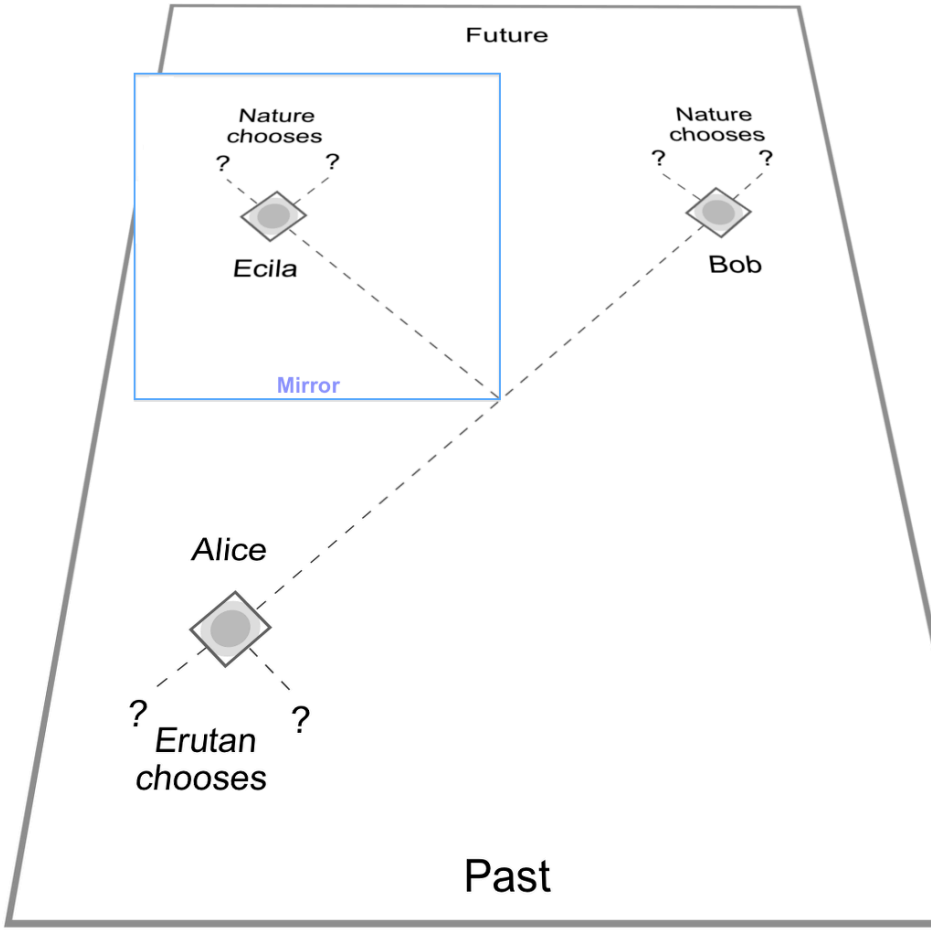

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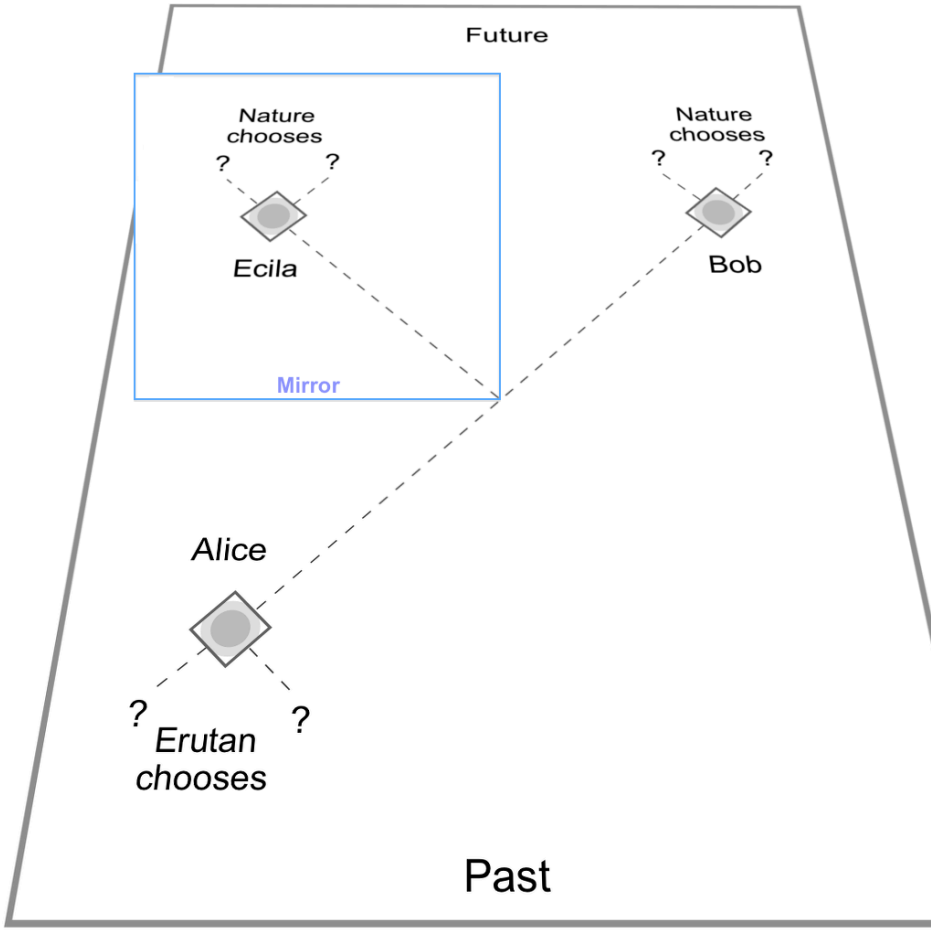

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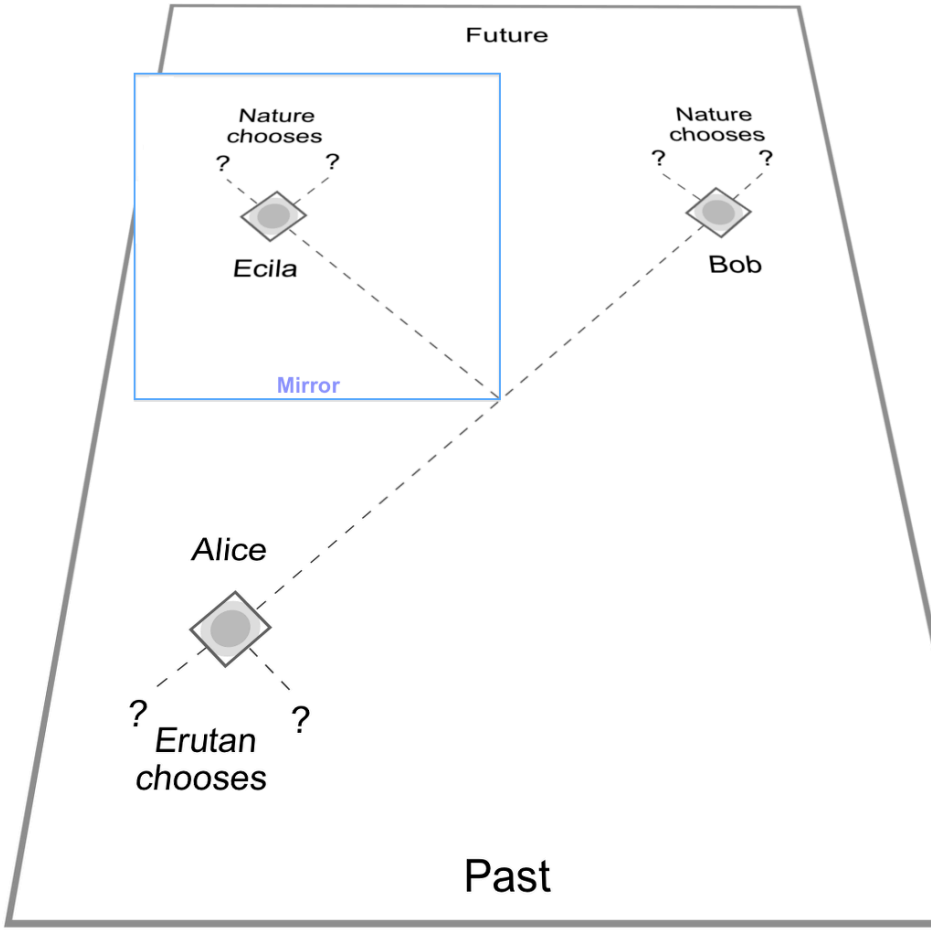

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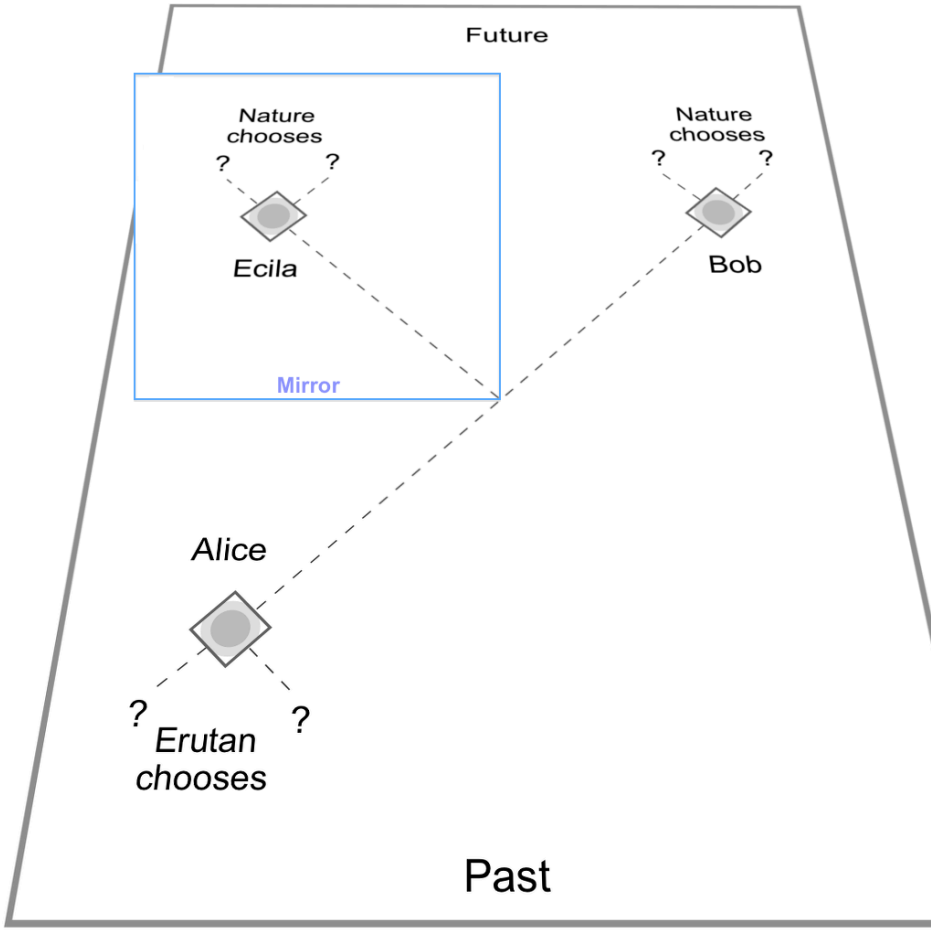

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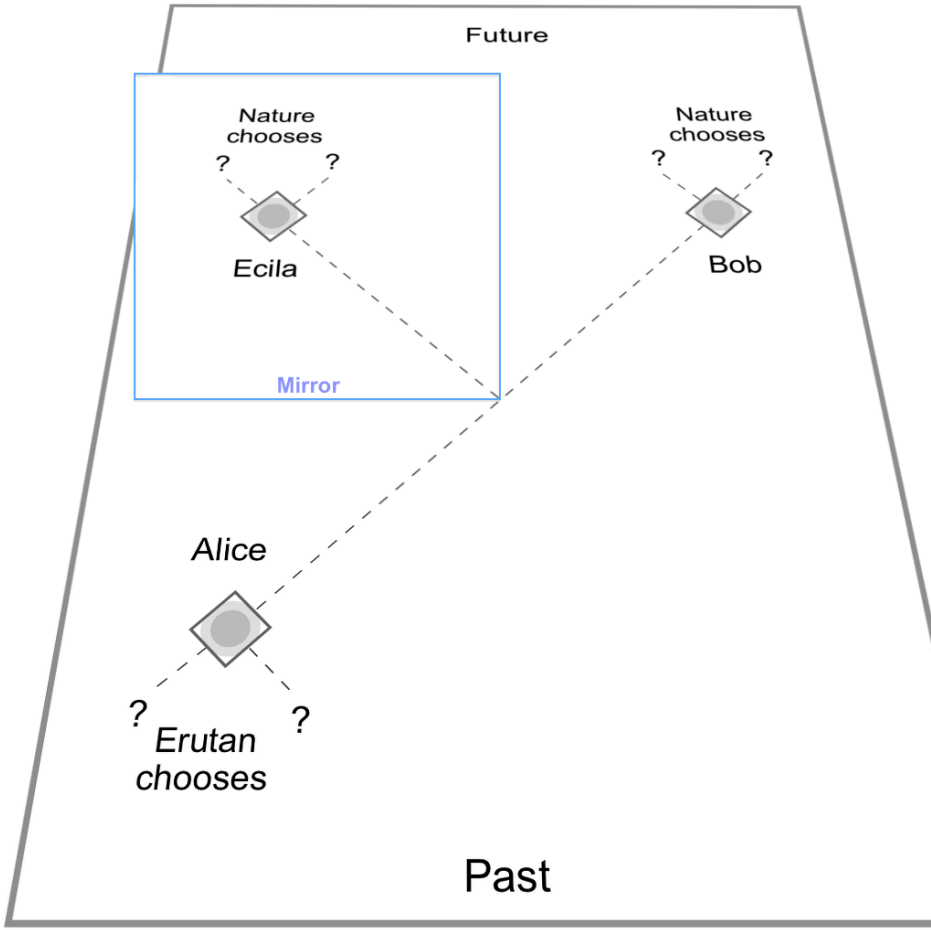

Two arguments for the Paris option

1. **Bell's Theorem**

   The usual formulation

   Locality + 'Independence' $(= \neg$**Retrocausality**$) \Rightarrow \neg$**QM**

   Equivalently

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   Transposing

   QM + 'No magic' (i.e., Locality) $\Rightarrow$ **Retrocausality**

2. **The new argument** [with Realism presupposed]

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The End

Further reading

1. H. Price, 'Does Time-Symmetry Imply Retrocausality? How the Quantum World Says "Maybe",' *SHPMP* 43(May 2012), 75–83 arXiv:1002.0906v3
2. P. Evans, H. Price & K.B. Wharton, 'New Slant on the EPR-Bell Experiment,' *BJPS* (2013) arXiv:1001.5057v3