# Chapter 15

## "Symmetric Spacetime Intervals"

*Credit – Far Side: "My brain is full" (need permission)*

## Serendipity

Where does this leave us? We have discovered a new invariant in relativity, a spacelike invariant – the symmetric spacetime interval, SSI (or symmetric interval for short). We have introduced the concept of the world ribbon, a quantum abstraction to match the relativistic abstraction of the world line, but the spacelike top edge of the world ribbon needs a specification.

Well…that's convenient. We need a spacelike interval, and we have a spacelike interval. Let's consider if they fit together.

## The Permutations

Assume two entangled quantum particles are measured across a spacelike interval. Collapse of the wave function was envisioned to occur along the top edge of the world ribbon. Therefore, expand the world ribbon concept to cover the case of a pair of entangled particles. In this example, the *joint world ribbon* spans the entire light cone.

In the current dogma, observers are free to assume that the first measurement in their frame of reference is the cause, whose effect is an *instantaneous* collapse, changing the state of the entangled partner particle. If this is the case, causality is temporal, but the top edge of the joint world ribbon is horizontal in every reference frame and *does not* Lorentz transform – yuk.

Call this the acausal case.

The symmetric interval implies that only one of the measurements is the cause, whose effect is to collapse the connection *along the symmetric interval*, changing the state of the entangled partner particle. If this is the case, the top edge of the joint world ribbon follows the symmetric interval and Lorentz transforms, but causality is *atemporal* – yuk.

Call this the causal case.

Both cases question deeply held assumptions about the nature of reality.

## The Acausal Case

Consider a sequence of EPR style entangled photons which are directed toward two spacelike separated observers who make polarization measurements, Alice in the orthogonal basis, Bob in the conjugate diagonal basis.

Add two observers, Darrel, and Darrel[1]. Darrel sees Alice make her measurement first, but the other Darrel sees Bob make his measurements first. What story do the Darrels tell about the collapse of the wave function?

In Darrel's frame of reference, the left going photons encounter Alice first. He sees Alice collapse entangled pairs from an EPR state to a state in the orthogonal basis. This is a random collapse, so Alice detects a random sequence of HV photons, but Darrel believes this collapse is instantaneous, so the right traveling photons simultaneously collapse in the orthogonal basis. Thus, Darrel believes a random sequence of HV photons is now headed toward Bob. Bob, however, makes measurements in the diagonal basis, so each arriving photon is in a superposition in the diagonal basis, thus it collapses a *second* time, this time in the diagonal basis, randomly. Bob detects a random sequence of DS photons.

In the other Darrel's frame of reference, the right going photons encounter Bob first. He sees Bob collapse entangled pairs from an EPR state to a state in the diagonal basis. This is a random collapse, so Bob detects a random sequence of DS photons, but Darrel believes this collapse is instantaneous, so the left traveling photons simultaneously collapse in the diagonal basis. Thus, Darrel believes a random sequence of DS photons are now heading toward Alice. Alice, however, makes measurements in the orthogonal basis, so each arriving photon is in a superposition in the orthogonal basis, thus it collapses a *second* time, this time in the orthogonal basis, randomly. Alice detects a random sequence of HV photons.

Remember Reason's uncertainty box.

Let's summarize. In one case, the first particle is measured in basis 1, takes on a random value, and the corresponding value is assumed by its entangled partner, instantly, which subsequently gets measured, and changes its value, randomly, to one of the eigenstates of basis 2. Or the second particle is measured in basis 2, takes on a random value, and the corresponding value is assumed by its entangled partner, instantly, which subsequently gets measured, and changes its value, randomly, to one of the eigenstates of basis 1.

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[1] In-joke from a famous skit in the *Bob Newhart* show: "This is my brother Darryl; this is my other brother Darryl."

At least each Darrel can compute what the other believes.

Both Darrels see Alice observe a random sequence of HV photons and see Bob observe a random sequence of DS photons. They agree on the measurements observed by Alice and Bob, but Darrel believes the photons on the *right* experienced two collapses, while the other Darrel believes that the photons on the *left* experienced two collapses.

But which photon gets collapsed twice is different between the two stories. We have incompatible descriptions of the history of these two particles. Recall that the statistical predictions of both stories are *identical*; there is no way to experimentally distinguish between them.

To claim that one measurement is first is not relativistically consistent; different observers will tell different causality stories.

If this is the way things are, if this is reality, then causality is not preserved; causality itself is no longer an invariant. The current dogma sucks.

Let's review, oh I don't know, say the last hundred years of physics. Mass is not conserved, nor is the old definition of energy, only mass-energy is an invariant. The spatial coordinates of events are not conserved, nor are the temporal coordinates, only the spacetime intervals are invariants. Charge is not conserved, nor Parity, nor Time direction, but CPT is an invariant. Dot, dot, dot. Early concepts of stuff, long thought to be conserved, are being supplanted by new invariants, invariants of things more subtle than 'stuff.' Must we now add causality to this list?

## The Causal Case

Well, that was rather unpalatable. Is the causal case any less so? There would have to be some aspect of the situation that allowed left and right to be distinguished. That's what the symmetric interval achieves.

Let a single pair of EPR entangled photons head in opposite directions, say left and right. Which measurement causes the collapse? We'll specify that a symmetric interval connects the two photons from birth to first measurement. As they separate, the SSI lengthens, but its slope remains constant.

The 12 light-second thought experiment of the previous chapter suggests an approach. As the velocity of the relativistic observer U changes, so do the frequencies of the emitted photons. One is red-shifted, the other blue-shifted. Identify the two photons as #1 and #2. The amount of shift is independent of the absolute frequencies of the photons, it depends only on the velocity of U. Therefore, the slope of the symmetric interval must be dependent upon only the ratio of the frequencies of the red and blue shifted photons. I'll spare the general reader the details of the derivation (but for the intrepid reader, the derivation is presented in Appendix A). Here is the derived formula.

$$\beta = \frac{\nu_2 - \nu_1}{\nu_2 + \nu_1} \tag{1}$$

Beta is the slope of the symmetric interval. Turns out it is equal to the velocity of the center of mass of the two photons. It has the same functional form in all reference frames. It's clear from the formula that for the symmetric interval to have zero slope, the frequencies of the two photons must be the same. Our working hypothesis is that collapse occurs along this slope. In the center of mass frame, where the frequencies of the two photons are the same, the collapse happens instantaneously. In other frames, collapse will happen either forward in time from one photon to the other, or backwards in time from the other photon to the one.

## Spacetime Diagram

To see how all these concepts play together Figure 2 shows a spacetime diagram of a simple experiment with a pair of EPR entangled photons. In the lab frame are two detectors; one 5 light-seconds to the left the other 7 light-seconds to the right. They are the vertical lines in the diagram. The two entangled photons follow the world lines of the light cone, +/- 45°. They will therefore be detected at these two spacetime coordinates; left at (-5, 5) and right at (7, 7). There is a frame of reference in which the two photons are detected simultaneously. Its plane of simultaneity is shown as the dotted line with shallow slope.

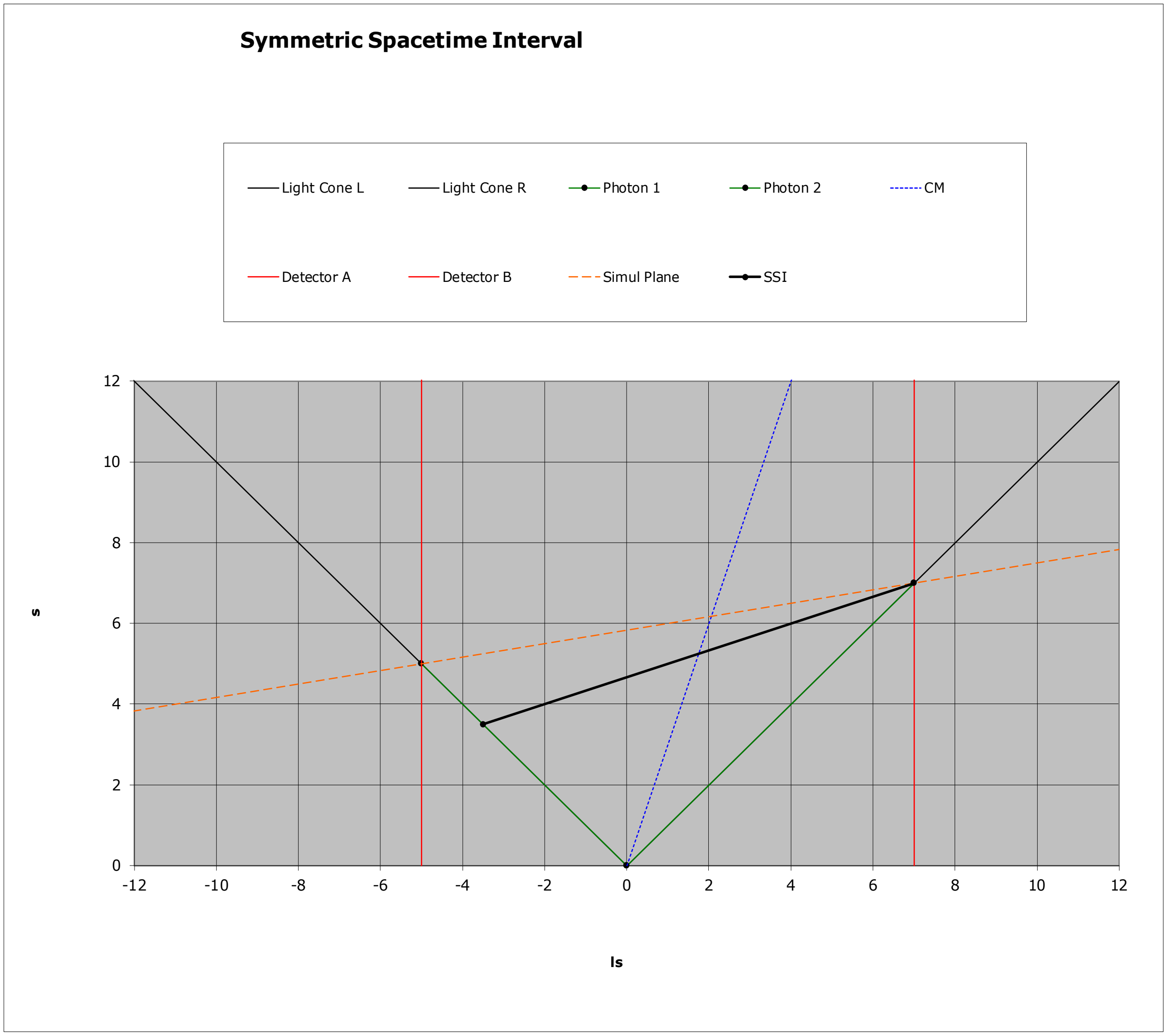

Figure 2 – **Symmetric Spacetime Interval for EPR Photons:** Vertical lines are the detectors, timelike dashed line the center of mass of the entangled photons, spacelike dashed line the plane of simultaneity for their simultaneous detection, and the spacelike solid line is their symmetric interval. There are four events of interest, indicated by dots; *creation* - the emission of the entangled photons at (0, 0), *encounter* - the detection of the first one (on the right) as the symmetric interval encounters the right detector first at (7, 7), *responder* - the collapse of the second photon (on the left) at the opposite end of the symmetric interval at (-3.5, 3.5) because the other photon was measured, and the *validation* - the detection of the second photon (on the left) at (-5, 5).

Now the two entangled photons are created, from the perspective of the lab frame, with different frequencies. This could be done by setting the source in relative motion, or by using nonlinear crystals cut at a higher harmonic. Therefore, the center of mass in the lab frame is not vertical; it is the steep dotted line, tilting to the right. This means the left heading photon is red-shifted and the right heading photon is blue-shifted. The shallow solid line is the symmetric interval. It is the plane of simultaneity for the reference frame where the frequencies of the two photons are the same.

The SSI allows us to tell one causality story, one that is relativistically consistent. There are four events in this story, starting with the *creation* event at (0, 0). Picture the symmetric interval between the time of creation and the time of detection as a series of snapshots. It grows in length always connecting the two photons and never changing its slope; each snapshot is parallel to all the others. Like the surf wave in the discourse. Eventually one end encounters a detector, the *encounter* event. That spacetime event (7, 7) is what causes the wave function to collapse. The other photon therefore makes the transition from entangled state to pure state at the opposite end of the symmetric interval. Call this the *responder* event. It happens at (-3.5, 3.5). 'Later' it is measured by the detector on the left; call this the *validation* event at (-5, 5).

What we have are two spacelike intervals, one stationary, one in motion. The stationary one is just the plane of simultaneity for the detections of the pair of entangled particles. The one in motion is the symmetric interval that connects the two entangled particles. Note that the symmetric interval will encounter the plane of simultaneity in the same direction for all observers. Call this a *zipline*. The relative angle determines whether the zipline is left to right, or right to left, but the direction of the zip is an invariant, it is relativistically consistent whether forward in time, backwards in time, or simultaneous. We have broken the isotropic nature of space, we can tell left from right; not universally, it is situation dependent, but spacelike causality can now be specified in a way that Lorentz transforms.

For the setup in Figure 2, collapse occurs backwards in time from right to left in the lab frame. However other frames of reference will see the collapse as occurring forwards in time, and for that one special frame where the symmetric interval is horizontal it sees the collapse as instantaneous. However, all reference frames agree on which detection is the encounter, and which the validation. They all agree on the direction of the zipline. They also all agree on which particle suffers a first collapse because the entanglement was broken and only later suffers a second collapse upon its final measurement.

We have one and only one causality story, and it is relativistically consistent. Thus, we posit that if spacelike causality is allowed in physics, it must happen along symmetric spacetime intervals.

But we pay a price for this. In some reference frames the present has occurred prior to the past, causality is unambiguous in terms of story, but past-present-future is no longer an invariant. If this is the way things are, if this is reality, then temporality is no longer preserved; causality can go backwards in time. Common sense insists that this too sucks.

There is one caveat; at this point we can't determine if wave function collapse occurs along symmetric intervals or ziplines. Whether this is significant or not will have to be left to later researchers. For now, either assumption is equally valid.

## A Broken Invariant Conundrum

It seems we are confronted with a conundrum; causality is broken, either it is no longer preserved, or it can go backwards in time. Both are uncomfortable. Perhaps the question to be resolved is which one seems less radical. Or better, maybe we can find a way to get nature to tell us which it is.

“So, what,” you say, “since the predictions are the same, regardless of who claims the first measurement, the idea of symmetric intervals is not testable.” This is true, for a simple EPR entanglement. It may turn out that the only way to validate the idea is to show FTL, and that requires a more sophisticated entanglement. For that, we may have to think out of two boxes at once. But if an FTL test can distinguish between causality being ambiguous or violating temporal order, it is worth the effort.

# Review

Quantum tic-tac-toe suggests that self-reference, with its natural nonlinearity, is necessary to solve the measurement problem, this overcomes the first objection to QTP. The symmetric spacetime interval resolves objections 2, 3, and 4 at once; it provides a privileged observer, a way to make collapse relativistically consistent, and a way to determine left from right which sidesteps the isotropic nature of space.

We are now ready to tackle the most challenging objection to spacelike causality – temporal paradox.