Hi Stevie,

Thanks again for your interest in quantum erasers, interference, and the like. I appreciate that you've thought reasonably carefully about the system and tried to make definite statements about what you believe or don't believe. That's *extremely* helpful in trying to pinpoint where any logic flaws might lie, and I can't tell you how much I wish that many more people did this as carefully as you have.

In general I rather agree with much of what you said, but not all of it. Starting from the end, it's definitely true that the fact that a quantum eraser can be done to reveal interference does seem to imply that the particle did not originally go through just one slit. However, I'm not sure that I would agree that the statement that "the particle hasn't actually traveled both or just one path until we find out which-way info, or erase which-way info". In my opinion, I think it would be appropriate to say that the particle *has* traveled both paths, at least to the extent that that would be the quantum mechanical description of the state after the slits. In particular, even if there are which-way detectors sitting by both the top and bottom slit, the passage of the photon through the slits—according to strict quantum mechanics—simply entangles the path of the particle with the state of those detectors. In other words, the initial state immediately after the slits (assuming that which-path detectors are after the two slits),
$\left(\left|up\right\rangle+\left|down\right\rangle\right)\left|-\right\rangle_{up}\left|-\right\rangle_{down}\Rightarrow\left|up\right\rangle\left|"Yes"\right\rangle_{up}\left|"No"\right\rangle_{down}+\left|down\right\rangle\left|"No"\right\rangle_{up}\left|"Yes"\right\rangle_{down}$ i.e., an entangled state in the path of the particle and the state of the two which-path detectors.

At least according to a strict interpretation of quantum mechanics when the particle is in the superposition state it is in some sense in both of these existences at once (one difficulty arises, however, in the case that the which-path detectors elevate the signal to the classical level, and we don't know that we can actually describe classical objects in terms of quantum mechanical superpositions—this is precisely the Schrödinger cat paradox); however, if we are assuming that we can eventually perform a quantum erasure measurement on the which-path detectors,that is certainly only true to the extent that they can be described by quantum mechanical wave functions, so for now I will assume that's true.

This then leads me to explain why I disagree with your second claim that "if the particle had traveled to both paths, then an interference would clearly result". It is our understanding that interference only results when the underlying processes that lead to a given outcome are indistinguishable; only then do we add the probability amplitudes, (which contains all the relative phase information), and then take the absolute square to reveal the final probability distribution. The interference shows up in the "cross-terms", which therefore reveal the relative phases between the different probability amplitudes (or, more physically in this example, the relative phases associated with the photons going from the source to the screen by the upper slit, or by the lower slit; as we look at different places on the screen these relative path lengths change, which is why the interference pattern changes from constructive to destructive and so on). The existence of the which-way devices, and the presumably distinguishable $\left|"Yes"\right\rangle$ and $\left|"No"\right\rangle$ states means that these cross-terms = 0, i.e., there is no interference. This is also discussed in the *Scientific American* article I sent, in which we do not observe interference between photons traveling through two slits with different polarizations, simply because there is a measurement which could be made which would distinguish which of the two slits the photons went through. So, this would lead me to prefer to say that even in the presence of the which-way detectors, the photon still has a probability amplitude for going through both slits.

And now we come to the heart of the problem. Namely, if we claim that the photon really did go through both slits, then how is it that we are never able to detect a photon in the upper path and the lower path at the same time? Obviously, this is impossible because there is only one photon, so it can only be detected at one of two detectors. Nevertheless, in a sense it would seem that we are stuck, if we interpret the wave function as saying that the photon actually existed in both paths at the same time. For this reason, the strict Copenhagen interpretation of quantum mechanics forbids us to actually make these claims, and only allows us to make statements about what we can actually calculate, i.e., the probabilities of various events depending on the setup of the experiment. Quantum mechanics always gets the right answer for these predictions. But it doesn't allow us to say anything about "what actually happened" to the photon between the source and the final detection screen, unless we actually measure it. This may seem bothersome, and I agree that it is completely troublesome.

Consequently, people have come up with various other interpretations of quantum mechanics, such as the many-worlds interpretation, in which the universe bifurcates every time a quantum decision occurs, so that, e.g., there is one branch of the universe in which the photon takes the upper path and a different branch of the universe takes the lower path. This does get around the philosophical argument of the photon being in two places at once. On the other hand, it leads to an enormously enormous number of universes, which many practicing physicists find to be unpalatable (but not disprovable!).

Another alternative interpretation of quantum mechanics is the so called de Broglie-Bohm guiding wave interpretation, in which the photons (particles) are like surfers on top of the quantum mechanical wave function. Each surfer only goes through one slit, but where the surfers go, and the possibility of observing interference effects is determined by the wave function which does go through both slits. It turns out that this interpretation is manifestly nonlocal, in the sense that making a measurement on one side of an entangled system will immediately, and nonlocally change the wave function at the other location. Again this is unpalatable to many physicists, but again, there's no way to actually prove this interpretation as being in some way "more correct" than any of the others.

Okay, I think I'll leave off the discussion there. Perhaps you will have other questions after you read the *Scientific American* article and the other article that I sent as well. I'm happy to try and answer as best I can. However, I suspect that many of your questions may fall into the realm of philosophy, in which case your interpretation is likely to be as valid as mine. Thanks for the discussion.

Best wishes,
Paul