Reply to “Comment on ‘Asking Photons Where Have They Been’ ”

Salih [1] proposed to consider a modification of our experiment [2] and argued that it cannot be explained well with the two-state vector formalism (TSVF) which we advocated. We will argue that Salih’s conclusions are invalid because he relied on a common sense argument: if it is true that a system has property \( A \) and it is true that it has property \( B \), then the system has properties \( A \) and \( B \) together. This argument fails for pre- and postselected quantum systems [3].

In our experiment we induced vibrations of mirrors with various frequencies inside an interferometer and argued that finding a frequency in the signal carried by the photons tells us that the photons bounced off the mirror with this frequency. In particular, we argued that the photons were inside a nested interferometer because we have seen in the power spectrum the frequencies of its two mirrors, \( A \) and \( B \). This was surprising since the detected photons could not pass through this interferometer.

Salih suggested to vibrate the mirrors in a synchronized way with the same frequency but with opposite phase, i.e. when mirror \( A \) is rotated by a small angle \( \delta \theta \), mirror \( B \) is rotated by the angle \(-\delta \theta \). These rotations lead to identical vertical shifts of the two beams toward mirror \( F \), see Fig.1b of [1], and do not disturb the destructive interference. Now, there is no wave leaking from the nested interferometer toward the quad-cell detector and, therefore, the frequency of vibrations of the internal mirrors should not appear in the power spectrum. Salih suggested that this fact cannot be explained in the framework of the TSVF.

The TSVF tells us that in our setup the weak value of projections of the photon on the mirrors are: \((P_A)_w = 1\), \((P_B)_w = -1\). This means that for any weak coupling, the effect of mirror \( A \) will be as if the photon as a whole was bouncing off mirror \( A \), while the effect of mirror \( B \) will be the opposite of the effect of the whole photon bouncing off \( B \). The effect on a photon bouncing off mirror \( A \) due to its rotation is identical to that of a photon bouncing off mirror \( B \) due to its rotation: both lead to a vertical shift in the same direction. Thus, the weak values “1” and “-1” tell us that the effects of the mirrors cancel each other and we expect cancellation of the signal.

Salih’s modified experiment does not indicate the presence of the photon near \( A \) and \( B \) because of the cancellation of the effects, exactly as Salih described in his fifth paragraph. However, in the next paragraph Salih argues that since a single photon cannot be simultaneously near mirror \( A \) and near mirror \( B \), the cancellation of the effect appears only after averaging on many photons, some shifted by mirror \( A \), others by \( B \). This is in contrast with the Schrödinger evolution picture in which every photon behaves in the same way.

Salih is mistaken in his description of the TSVF picture. Each pre- and postselected photon is described by the same two-state vector. All photons are present in \( A \), \( B \) (and \( C \)), so every photon is not shifted because the shift in \( B \) cancels the shift in \( A \).

Salih reaches his conclusion because he uses the following classical common sense argument. If it is false that the photon was both in \( A \) and in \( B \), at least one of the statements: “the photon was in \( A \)”, “the photon was in \( B \)” has to be false too. This is similar to the Hardy paradox [4] in which the electron passes through an intersection, the positron passes through the intersection, but the electron and the positron do not pass through this intersection together. In our case both statements “the photon was in \( A \)” and “the photon was in \( B \)” are true since in both places the photon leaves a trace. In the experiment the trace is left on the spatial wave function of the photon. The traces are equal shifts in the opposite directions, so they cancel each other and we see nothing. The vertical position of the beam is the pointer of the weak measurement of the sum of the projections. The sum rule holds for weak values, so \((P_A + P_B)_w = (P_A)_w + (P_B)_w = 0\). The product of the projections vanishes, as Salih mentions, and the weak value of the product vanishes too, but the product rule does not hold for weak values, so no contradiction arises, see [5] for gaining intuition for similar situations.

Salih ends his comment arguing that the TSVF also does not allow the analysis of the case when the channel \( C \) is blocked. Yes, in this case the simple TSVF analysis fails because the weak values become singular. Since the postselected state is orthogonal to the forward evolving state, formally, the postselection is impossible, but due to disturbance, some photons will be postselected. The analysis of this situation in the framework of the TSVF is less elegant, but possible, see [6,7], and it does provide a way to calculate the size of the peaks which were too small to observe in our experiment.

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