A photon's therapy session

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Photons thrive in our lab. Their nature is shy and they don't really know how to interact with each other. They come to our lab looking for advice. As scientists, our job is to guide them such that they connect and sync with one another.

If you're now thinking - *why do I care? I'm not even sure what a photon is* - I'm here to tell that you've come to the right place. This is an article about the strength of cooperating photons, their journey and how they can help us. And since you ask, as far as this story is concerned, a photon is the particle of light that, among other things, allows us to see the world around us [1].

I. INTRODUCTION TO PHOTONS' BEHAVIOUR AND THERAPY GOALS

As a first step, it is important to note that our photons' (much like a grumpy teenager's) vocabulary is limited to 0 and 1, which means that when we ask them questions (measure them) these are their only two possible answers (**outcomes**). They might have never thought about your questions, so the outcomes might be decided on the spot, instead of predetermined. This behaviour is predominant when you ask a sequence of very different questions. For example, let's say you choose to ask X, followed by Y and then Z. If you repeat the sequence, the answers might change from the ones given the first time. Also, as expected, the outcome to the same measurement might also change over time, depending on their journey but if you consecutively ask the same question, they are consistent. After some experience, we start to know what to expect, although they are never fully predictable. Tough patients... These are some examples that highlight the concept of **superposition** and **projective measurement**. There are other important features that we are going to skip for the sake of sticking to the main focus of this story - the power of cooperating photons.

When we are successful in our sessions, we can guide the individual photons to interact with each other, possibly entering in a specific state of cooperation - **entanglement** - that we wish to explore. In this state of entanglement, if we ask the right questions, they will all immediately give you the same answer - it can be either 0 or 1 but it will be the same for all. This happens no matter how far apart they are and without them knowing what outcome the others are going to give. They are truly in sync. We approach this in group sessions, for which we gather up to four photons and walk them through a series of optical elements, namely beam splitters, a non-linear crystal, and a few more. We've seen that when they are in good alignment towards the end goal, we can achieve very promising results.

II. THE ROAD AHEAD

After a successful group session, it is now time for the photons to fly and explore new paths. If we are lucky, they will reward me with good results for my research us humans with trustworthy connections, by strengthening our communications with **security, anonymity and privacy**.

To explain what this means, it is useful to note that the scenario we usually consider, when we ask our photons for help, is the following: a group of people wants to communicate in some way - some examples will follow soon - but they are far away from each other; let's say each person/**player** can be represented as a **node** in a **network**; different nodes are **linked** if they share entanglement, i.e., if each player has a photon that is entangled with the photons on the other nodes. It becomes clear that the bigger the number of photons in the group session, the bigger is the network we can form.

In successful group sessions of two photons, they allow us to teleport information, i.e., a message can go from node A to node B without being physically sent. Group sessions of multiple (more than two) photons allow us to share a secret without revealing our identity, to have secure elections while maintaining the anonymity of the vote, among other things. In other words, entangled photons are a great security and anonymity guarantee for a wide variety of communication applications. Now, you might think that we already do all that, so why do we need to entangle photons? Although that is partially true, nowadays, our security is based on the computational complexity of solving a specific problem associated with the message decryption. But what if someone finds a smart and simple way of solving that problem? The security would be jeopardized. In our lab, we want to avoid that and, instead,

[1] for a more rigorous description please check out a quantum mechanics/optics textbook.

solely rely on the validity of physics and on our experimental ability to entangle photons. In other words, if the laws of physics are true, we are safe, no smart way getting around that.

In real life, however, there are a lot of variables out of our control. For example, how do we know that the photons we're using are actually entangled and not just pretending? Or that the photons didn't lose their connection while they were flying in the network? Or that other people in the network don't have a secret plan, arranged with the photons, to trick us? One approach could be to work on our trusting issues. Alternatively, we could trust all of those external variables but this could possibly jeopardize the safety we are trying to achieve. Luckily for us, there is a third option. It turns out that by asking the photons individually and repeatedly a set of random questions enough times, we can avoid being tricked. This is because there is a very distinct pattern of answers to the questions - commonly referred to as correlated measurement outcomes, in case you're wondering - that only photons that are truly entangled can exhibit. This is a generalization of the example mentioned before, when we first introduced the concept of entanglement. In other words, as long as we are sure that there is no communication between the nodes of the network during the inquiry and that the questions are independently and randomly selected, we can very confidently conclude, from the analysis of the Q&A pattern, if we succeeded to entangle our photons. We can then get our communications going without suspicions. This process goes by the name of **quantum state verification** and it is included in the routine of a wide variety of communication tasks.

III. CONCLUSIONS

Some of the previously mentioned tasks are examples of the next steps in our photons' journeys. Even though I only touched the surface of how we guide them, the possible applications and how they are realized, the thing that I want to stress the most is that these tasks are only possible because the photons have achieved this cooperative state. The privacy, security and anonymity of these protocols are a direct result of it. We can certify all of those properties are present in our communications by verifying their entangled state, since it has such distinct features. Not only it is a beautiful phenomenon, to observe them in such sync, but we also get to enjoy the perks that come with it. We are really looking forward for the rest of this journey.