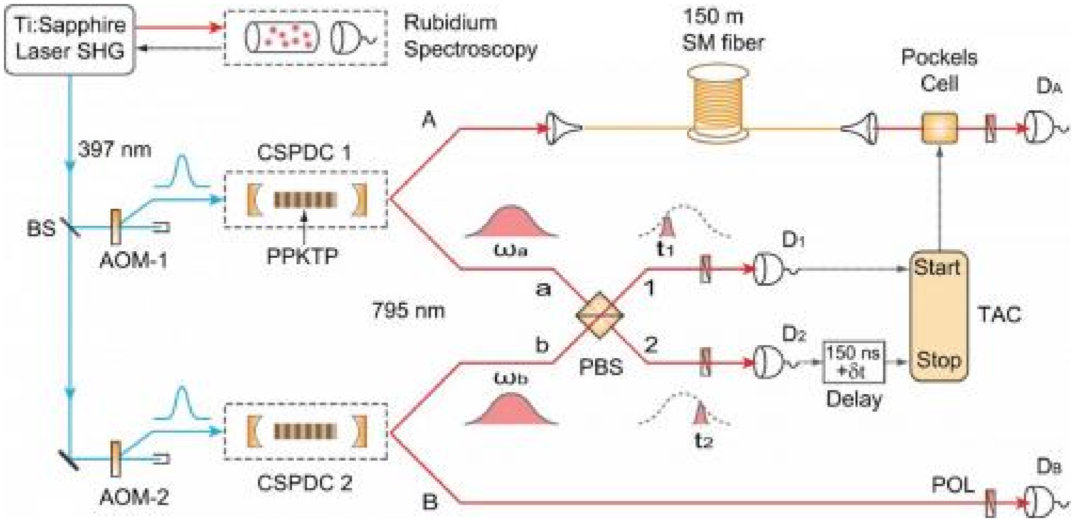
A cure for clashing qubits: Researchers successfully entangle different-color photons

April 2 2014, by Stuart Mason Dambrot



Experimental setup. Two cavity-enhanced spontaneous parametric down-conversion (CSPDC) sources are being used to create two pairs of entangled photons. The pumping beam is generated though second-harmonic generation (SHG) of a Ti:sapphire laser working at 795 nm and stabilized through rubidium spectroscopy. Two acousto-optic modulators (AOM) are used to chop the pumping beam into short pulses with a repetition rate of 2 MHz and to tune the frequencies of the narrow band entangled photons. Each entanglement source is basically made up of a linear cavity with a 25 mm long nonlinear crystal (PPKTP) and a 5 mm long KTP crystal inside. The KTP is utilized to achieve double resonance for both CSPDC photons through temperature tuning. The measured linewidths for the two cavities are $\gamma1/2\pi$= 4.2 MHz and $\gamma2/2\pi$= 5.6 MHz, respectively. Within each source, by controlling the double-resonance condition and making use of additional filtering etalons [16], the two down-converted photons are configured to have the same frequency, which is exactly one-half of the pumping beam. Photons A and a are polarization entangled, and so are B and b. A polarizing beam splitter (PBS) along with two polarizers (POL) are utilized for the Bell-state measurement. Detection-time differences between D1 and D2 are fed forward to a Pockels cell to cancel the random phase shifts in order to recover the entanglement between photons A and B. To compensate the feedback delay due to the single-photon detectors, the time-to-amplitude convertor (TAC), and the high-voltage driver of the Pockels cell, a single-mode (SM) fiber loop with a length of 150 m is inserted for photon A. Credit: Reproduced with permission from Zhao, Tian-Ming et al, *Physical Review Letters* 112, 103602 (2014), doi: 10.1103/PhysRevLett.112.103602

(Phys.org) —While two-photon interference is an important way of entangling independent *identical* photons, it does not handle different-color photons with the same aplomb. Recently, scientists at the University of Science and Technology of China developed time-resolved measurement and active feed forward, and in a groundbreaking achievement used these techniques to successfully entangle two independent photons of different colors for the first time. The researchers reported two key findings: They showed entanglement with a varying form for different two-photon temporal modes through time-resolved measurement, and converted the varying entanglement into uniform entanglement using active feed-forward. Moreover, the scientists state that their study also provides a potential solution to the frequency-mismatch problem characterizing the interconnection of dissimilar quantum systems in future quantum networks.

Prof. Xiao-Hui Bao discussed the paper that he, Prof. Jian-Wei Pan (who leads their research group), Researcher Tian-Ming Zhao and their co-authors published in *Physical Review Letters*. The scientists encountered a number of challenges in entangling two independent photons of different colors by exploring and developing time-resolved measurement and active feed-forward – for example, in selecting entangled states out of otherwise totally mixed states, the first hurdle was using time-resolved measurement. "In order to erase the distinguishable information in frequency, we have to detect the photons with a precision that is much faster than the inverse of the frequency separation," Bao tells Phys.org.

For their experimental parameters, this required a measurement precision of better than one nanosecond (1 ns). In addition, in order to understand the random phase of the two-photon output state, the scientists had to use time-resolved measurements and register the detailed time information for each event – a procedure that Bao says is much more complex than the traditional multi-channel time coincidence technique.

"Two-photon interference is a widely-used method for entangling independent photons – for example, in the polarization degree – by using two-photon interference," Bao says. However, he points out that this method doesn't work if the two photons have different colors. "We've found out that the two output photons are no longer entangled simply because their joint state in the polarization degree is correlated – that is, *actually* entangled – with their temporal degree. For different combinations of temporal modes, he explains, the joint polarization state is still entangled but with different forms. This means that without knowing the temporal information, the polarization state for the two photons is a mixed state. "Thus, we propose to make time-resolved measurements to resolve the temporal information and use active feed-forward to get the polarization entanglement recovered."

Another challenge was converting the varying entanglement into uniform entanglement using active feed-forward. "In order to get entanglement recovered by using active feed-forward," Bao explains, "the key challenge is to make the whole system respond extremely fast, since photons have to be delayed to wait for the feed-forward operations. Our experiment involved a 150-meter fiber delay, which means that the maximal overall delay of the whole system including time-resolved measurement and active feed-forward had to be less than 750 ns."

The scientists also had to determining how to measure the photons' temporal modes without destructing the polarization modes. "According to our theoretical analysis," he notes, "in the case of two different-color photons, if the time information is available with high precision the photons may still entangle each other by applying further feed-forwarding operations." However, he points out that for a two-photon experiment, in order to obtain this time information and apply feed-forward, non-demolition measurement has to be used – a highly-demanding technique that, unfortunately, is currently unavailable.

The researchers addressed these challenge in several ways. "Previous to our work it was known that by making tight temporal filtering, it is possible to entangle different-color photons through two-photon interference," Bao points out. "However, this method is extremely inefficient. On the other hand, our new method enables the entangling of different-color photons to become much more efficient by making use of time-resolved measurement and active feed-forward. This is the key insight of our work. Bao notes that in order to demonstrate our scheme experimentally, the researchers introduced three technological developments that, he adds, "could be rather useful for future experiments."

- In order to eliminate the difficulty of using non-demolition measurements in a two-photon experiment, the scientists demonstrated their scheme in a four-photon experiment by making use of the entanglement swapping process.
- By using the cavity-enhanced spontaneous down-conversion technique, they created two pairs of entangled photons with an adjustable frequency separation.
- To recover the entanglement, they developed a fast time-to-phase

> feed-forwarding system with an overall systematic delay of 360 ns – and within this system, designed a home-built circuit that measures the photon arriving times with a precision of 40 picoseconds (40 ps), and controls the voltage applied to the electro-optic modulator accordingly.

Bao notes that their research provides an approach for solving the frequency-mismatch problem for the interconnecting dissimilar quantum systems, and thus may become an essential tool for future quantum networks. "In our current experimental demonstration, we've made use of two pairs of entangled photons, with the interfering photons having different colors. With a tiny modification – replacing the photon-photon entanglement with photon-matter entanglement – it becomes straightforward to entangle remote dissimilar matter systems through interfering different-color photons." Bao emphasizes that this type of remote matter-matter entanglement is the most important element for a quantum network.

In the next steps in their research, Bao says, the scientists are planning to improve this technology further to allow larger frequency separations and make use of this technology to connect dissimilar matter systems directly. "Moreover," he adds, "we're also considering the possibility of combining the wavelength-division multiplexing technique with our method to extend the quantum communication bandwidth."

Bao also describes how their research relates to other areas in quantum physics, one such area being *blind quantum computing*, in which the input, computation and output all remain unknown to the computer. "In blind quantum computing, since a quantum transmission from a client to a server is required, frequency mismatch could be an issue – for instance, a fast-moving client will get its emitting photons shifted in frequency, and hence in color. Therefore, our work could possibly be applicable."

In classical telecom communication, he adds, the technique of wavelength-division multiplexing (WDM) is utilized ubiquitously to increase bandwidth. In quantum communications, WDM could also be used.

Nevertheless, different WDM channels have different frequencies. "Our work might have important application in making connections between different WDM channels."

Addressing other areas of research that might benefit from their study, Bao tells Phys.org that, excluding the field of quantum networks, "the area of linear optical quantum computing will definitely benefit from this study."

More information: Entangling Different-Color Photons via Time-Resolved Measurement and Active Feed Forward, *Physical Review Letters* 112, 103602, Published 10 March 2014, doi:10.1103/PhysRevLett.112.103602

Citation: A cure for clashing qubits: Researchers successfully entangle different-color photons (2014, April 2) retrieved 20 April 2024 from https://phys.org/news/2014-04-clashing-qubits-successfully-entangle-different-color.html