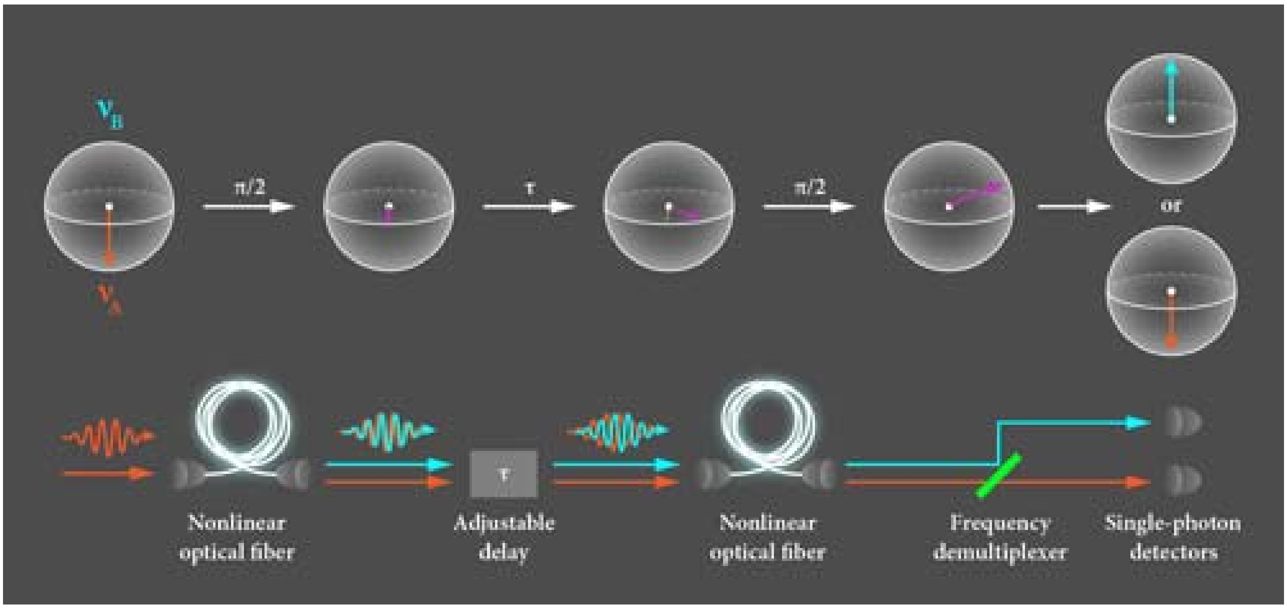
Color Duality in Photons

Conventionally, quantum frequency conversion is used to as fully as possible transfer photons (coherently) from one frequency to another. This is for different reasons, e.g. to improve detection efficiencies or to convert photons used for quantum communication to the telecommunication band for lowest loss transmission through optical fibers.

But what happens if one stops exactly “half-way” in the conversion process? Quantum mechanically one ends up with a color-super-position state of a single photon being simultaneously at two different color (frequency) states. This is exciting and interesting. But how to proof one really has a proper (coherent) quantum-superposition state? And is this maybe even useful for something?



APS/Alan Stonebraker
The illustration shows the conversion of a photon of one frequency, or color, into a photon that is in a quantum superposition of two colors, and the subsequent verification of this super-positions coherence with Ramsey spectroscopy.

For other quantum systems (like spins of single electrons, single atoms/ions…) such energy superposition states between a ground and excited (electronic) state very are well known. One way to produce them is to apply a so called Pi/2-pulse. By then letting the system freely evolve (and pick up a phase) and subsequently applying another Pi/2-pulse one realizes a so called Ramsey Interferometer. And this type of quantum interferometer is very widely used for a plethora of applications.
So, to demonstrate that one indeed can generate single photons in a genuine quantum super-position of two colors and that this might even be useful for something, the goal was to for the first time realize Ramsey Interference with single photons. The technical challenge of this is, that the quantum frequency conversion has to work so well, that one can cascade two conversion processes and implement a controllable phase in between. And this is exactly what we did.

As a side-remark, in all “traditional” Ramsey Interferometers there is always the possibility that the quantum superposition of the ground and excited state spontaneously decays into the ground state by coupling to the electro-magnetic (vacuum) field. For photons, which are themselves the quanta of the electro-magnetic field, no such decay channel (at least in vacuum) exist, making it fundamentally special.

The paper “Ramsey Interference with Single Photons”[1] and accompanying Viewpoint “Photon Qubit is Made of Two Colors” [2] have been selected as one of the Highlights of the Year 2016 by APS Physics. It was co-authored by Dr. Sven Ramelow, who recently started his Emmy-Noether-Group at the Institute for Physics, Humboldt-University Berlin, and is associated with IRIS Adlershof. While there have numerous highly interesting papers in Physical Review Letters in 2016, APS Physics explains their selection, writing: “It’s no surprise that LIGO’s discovery of gravitational waves tops our list of favorite Physics stories in 2016. The other slots went to research that marked a change in perspective, demonstrated an impressive experimental feat, or simply made us think.”

Incidentally, Dr. Sven Ramelow is working on follow-up ideas of this paper and the corresponding experiments, which he looks forward to soon being implemented at IRIS-Adlershof and the HU Institute for Physics and yielding new intriguing results.

APS/Alan Stonebraker

[1] **Ramsey Interference with Single Photons**
S. Clemmen, A. Farsi, S. Ramelow, A.L. Gaeta
Phys. Rev. Lett. 117, 223601 (2016)

[2] **Viewpoint: Photon Qubit is Made of Two Colors**
P. Treutlein
Physics 9, 135 (2016)