Experimental Realization of Teleporting Hybrid Quantum States

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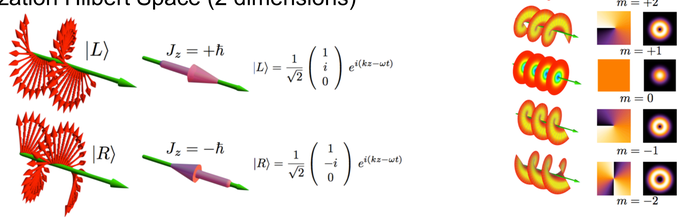
Abstract

Quantum teleportation is a very exciting concept in the modern quantum theory. It has vast relevance in areas such quantum communication, and quantum key distributions that allows for an increase in communication channel capacity and channel security. Experiments showing the teleportation of a bi-dimensional quantum system (qubit) have been achieved, though previous works has failed to look at teleportation of higher dimensional quantum states (qudit). This will be conducted by designing a source allowing us to entangle the polarization of four photons by methods of spontaneous parametric down conversion. By utilizing the entangled photons, observations of the quantum behavior of light can be analyzed alongside this we will be able to test for quantum teleportation of ququat quantum system. Moreover teleportation over different degrees of freedom of particles (i.e. hybrid quantum states) may increase the security since generations and detections of the apparatus are different. In this work we propose and examine teleportation between spin and angular momentum degrees of individual photons, in which any arbitrary polarization states of one of the entangled photons is teleported to an orbital angular momentum degrees of freedom. The ability to conduct quantum teleportation on higher dimension quantum states is of utmost relevance when discussing the potential applications of quantum information science.

Introduction

- Quantum teleportation is one of the most exciting concepts in modern quantum theory, though it is often misunderstood
- The use of quantum teleportation is important in quantum communication through the increase in channel capacity as well as security
- Teleportation of information (qudit) from one Hilbert space to another, as compared to teleportation of matter
  - Angular Momentum Hilbert Space (infinite dimensions)
  - Polarization Hilbert Space (2 dimensions)



- Teleportation of polarization degree of freedom of photon onto angular momentum degree of freedom of photon

Theory

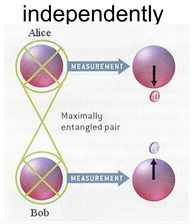
- Qubit: Superposition of states 0 and 1
  Teleportation from qubit to qubit

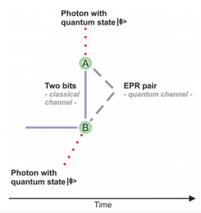
$$|\psi\rangle = \alpha\,|0\rangle + \beta|1\rangle \qquad |\alpha|^2 + |\beta|^2 = 1$$

- Bell States: Class of entangled states at which two quantum states are maximally entangled

$$|\phi_l^{\pm}\rangle_A = \frac{1}{\sqrt{2}}\Big(|h_l, H\rangle \pm |v_l, V\rangle\Big)_A$$
$$|\psi_l^{\pm}\rangle_A = \frac{1}{\sqrt{2}}\Big(|v_l, H\rangle \pm |h_l, V\rangle\Big)_A$$

- Spontaneous Parametric Down Conversion (SPDC)
  - A method to produce entangled photon pairs
- Quantum Entanglement: Quantum state of a particle cannot be described independently





References

[1] Manuel Erhard, Hammam Elyas, Harjaspreet Mand, Ebrahim Karimi, and Robert Boyd "Experimental Realization of Teleportation of Hybrid Quantum States", In Preparation
[2] Zhi Zhao and Yu-Ao Chen "Experimental demonstration of five-photon entanglement and open-destination teleportation", Letters to Nature

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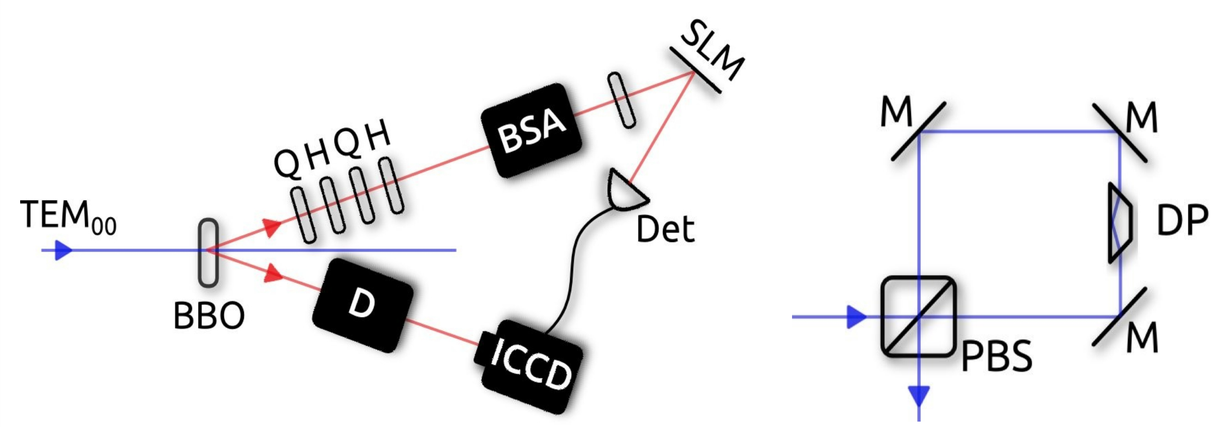
Experiment

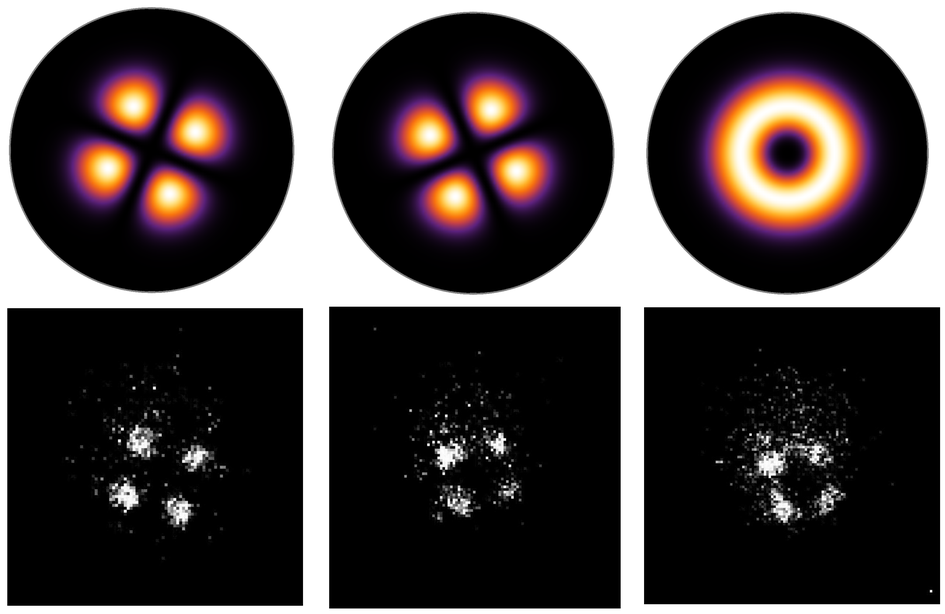


A sketch of the experimental setup used in examining quantum teleportation

A more detailed look at the Sagnac Interferometer used in projecting the $|X_1\rangle$ state onto one of the bell states

Results

Probability Density Plots



H Polarization | A Polarization | L Polarization

Conclusions

We have demonstrated that quantum teleportation hybrid quantum states is experimentally possible. The next step in this research would be to adjust aligning of the setup in order to obtain results which agree more closely with theoretical predictions. As well further research could deal with analyzing entanglement and teleportation of the multipartite regime (5 photon).