Light and matter intertwined: entangled two-photon interferometry

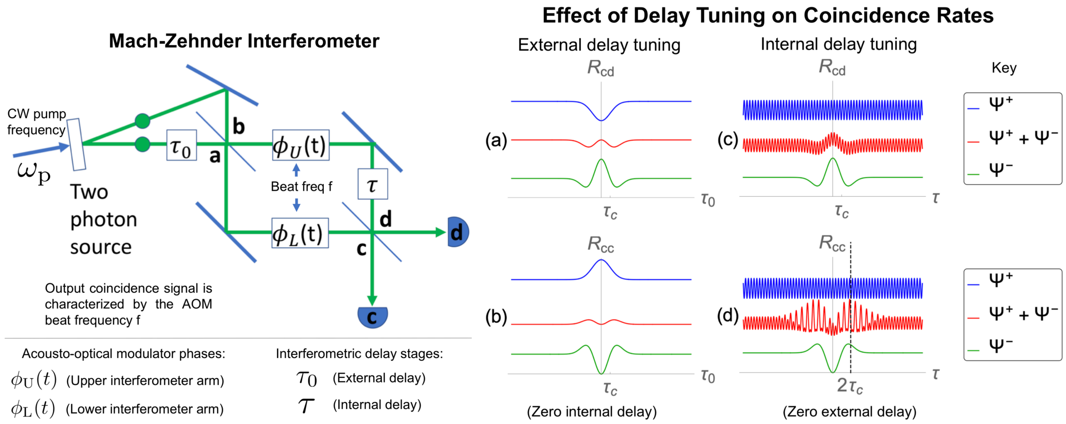

Figure 1: (Left) Oregon apparatus. (Right): Predicted joint output photon detections as various interferometer paths are changed, which depend dramatically on the symmetry of the two-photon joint quantum amplitude.

In quantum mechanical experiments, one generally performs many measurements to construct the complex *square* of the wave function for the quantum system in question. However, measurement of the wave function *itself* for even a single quantum particle (that is, both its amplitude *and* its phase), remains challenging. When multiple particles are considered, this task is further complicated by concept of quantum entanglement, in which the system as a whole may not be coherently described with reference to its individual constituents alone. *In a sense, for multiparticle quantum wave functions, the whole is more than the sum of its parts.*

This project explores ways to experimentally probe a global property of a two particle quantum system known as exchange symmetry. When a two-photon state is created in the lab, it will have well-defined *joint spectral amplitude*, a complex-valued function of two frequency arguments that gives the quantum probability amplitude for the two photons to be measured at particular frequencies (i.e., colors). The joint spectral amplitude may be a symmetric function, antisymmetric, or neither with respect to exchange (swapping) of the two frequency arguments.

At the Oregon Institute for Molecular and Quantum Science, an interferometer has been built (see Fig 1) to perform spectroscopy on molecular samples of interest by analyzing the joint output signal of an entangled two-photon input state, after interaction with a sample within (see `https://tinyurl.com/49n9728x`. During a leave there, Dr. Leary predicted that this apparatus could be modified to probe the symmetry properties of the joint spectral amplitude of quantum-entangled photons, making possible an experimental window into the strange world of two-particle quantum wave functions. As various interferometer path lengths are changed, the predicted joint output signal depends dramatically on whether the joint spectral amplitude is symmetric (blue), antisymmetric (green), or asymmetric (red)— (see Fig 2).

In this project, we will build on the work of Wooster graduates Ben Stern '22, Olivia Green '23, and Madelyn Noll '24, modeling theoretically how the output signal: 1) reflects the quantum wave function of light, and 2) characterizes quantum interactions with samples within the device. In short, the quantum properties of both light and matter are intertwined via the measured interferometric output signal.