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The duality relationship in the presence of post-selection

The duality relationship is one of the building blocks of quantum mechanics. Englert formally stated it as “The observation of an interference pattern and the acquisition of which-way information are mutually exclusive”. This principle has been put to the test many times, including Kwiat et al., who labelled each path of a Mach-Zehnder interferometer with polarisation to measure which-way information and the resulting interference pattern. In all of the experimental tests, the duality principle always prevailed. However, in a recent experiment, Menzel et al. conducted an experiment that reported high which-way information and high visibility fringes in a single experiment. They used pairs of photons entangled in position and momentum generated though spontaneous parametric down-conversion (SPDC) with a type II BBO crystal and an HG01 pump mode.

In this work, we investigate the duality relationship for light beams containing orbital angular momentum in the presence of post-selection. We investigate a two-dimensional subspace of OAM where different OAM states can be labelled with different polarisations. The coupling to the polarisation degree of freedom introduces a controllable non-seperabilty between the mode's internal degrees of freedom. This coupling gives the ability to report high "which-OAM" state and high "fringe visibility" measurements conditioned on successful post-selection of a particular polarisation. Our analysis highlights the importance of fair sampling in measurement procedures applied to the duality principle.