Superresolution measurements and the quantum Gouy phase in transverse-spatial N00N states

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Photonic N00N states, i.e., states of light where N photons are in an extremal superposition between two orthogonal states $\frac{1}{\sqrt{2}}(|N,0\rangle + |0,N\rangle)$, have an increased phase-sensitivity in comparison to their classical counterparts. Using the sensitivity offered by N00N states, in conjunction with the intrinsic properties of transverse-spatial modes, enables measurement schemes with sensitivities beyond the classically allowed limits and opens up possibilities to investigate the behaviour of different quantum states. In the present

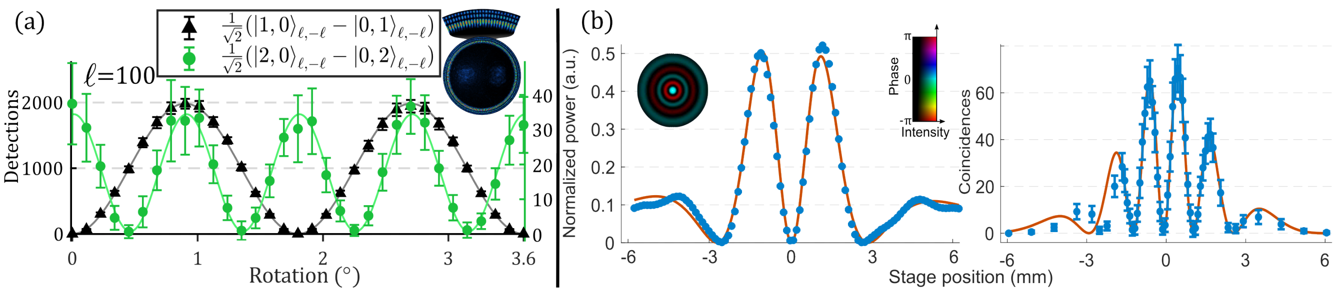

Figure 1: (a) An example of rotation measurement displaying superresolution with OAM $= 100\hbar$. (b) Interference data showing the Gouy phase evolution for a laser superposition (left) and two-photon N00N state superposition (right), with radial modes of index 0 and 4.

work, we first harnessed the angular sensitivity of orbital angular momentum (OAM) modes and create two-photon twisted N00N states for arbitrary OAM values through photon bunching [1]. We then use these twisted N00N states to demonstrate angular superresolution, in a single beam (see fig. 1(a) and [2]). We next utilized the same photon bunching process to create radial mode N00N states to probe the Gouy phase of photon number states and explored their significance in interpreting the origin of the Gouy phase, possible superresolution experiments, and the effective de Broglie wavelength of photon number states (see fig. 1(b) and [3]). Our results demonstrate that by simply engineering the quantum state and spatial profile of a set of photons, we can achieve quantum enhanced measurement precisions in a variety of tasks and study new phenomena which could have implications for future applications and our understanding of quantum mechanical concepts.

[1] M. Hiekkamäki and R. Fickler, *Phys. Rev. Lett.* **126**, 123601 (2021)

[2] M. Hiekkamäki, F. Bouchard, and R. Fickler *Phys. Rev. Lett.* **127** 263601 (2021)

[3] M. Hiekkamäki, R.F. Barros, M. Ornigotti, and R. Fickler *arXiv preprint arXiv:2206.01973* (2022)