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Deterministic Free-Propagating Photonic Qubits with Negative Wigner Functions

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Engineering quantum states of free-propagating light is of paramount importance for quantum technologies. Coherent states ubiquitous in classical and quantum communications, squeezed states used in quantum sensing, and even highly-entangled cluster states studied in the context of quantum computing can be produced deterministically, but they obey quasi-classical optical field statistics described by Gaussian, positive Wigner functions. Fully harnessing the potential of many quantum
engineering protocols requires using non-GaussianWigner-negative states, so far produced using intrinsically probabilistic methods.

We will present the first fully-deterministic preparation of non-Gaussian Wigner-negative freepropagating optical quantum states. In our setup, a small atomic cloud placed inside a mediumfinesse optical cavity and driven to a highly-excited Rydberg state acts as a single two-level collective “superatom”. We coherently control its internal state, then map it onto a free-propagating light mode to produce an optical qubit $\cos(\theta/2)\,|0\rangle+\sin(\theta/2)\,|1\rangle$ encoded as a quantum superposition of 0 and 1 photons. Its single-photon character is revealed by photon correlation measurements showing strong antibunching with a residual 0.5% probability of having two photons per pulse. The generated states are emitted in the desired spatio-temporal mode with a high 60% efficiency. Using an homodyne tomography we measure the density matrix leading to Wigner functions. In agreement with theoretical predictions, these functions are quadrature-squeezed for small qubit rotation angles θ, and develop a negative region when θ approaches π and the one-photon component becomes dominant. Our platform featuring a new approach of cavity quantum electrodynamics realizes a long sought goal of quantum optics, while holding promises for photonic quantum engineering applications.

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