

Multiphoton Spatial Correlations

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Quantum mechanics is a statistical theory, and statistics has paradoxes of its own. We show that the bunching of photons from classical states of light—thermal light, as in Hanbury Brown and Twiss, or random-phase coherent states—is an instance of Simpson’s paradox [1]: Glauber’s N -photon detection probability is exactly a P -weighted mixture of products of one-body densities. When $P \geq 0$, the photons of each realization are detected independently, from a geometry that breaks the symmetry of the state (a dipole of random orientation and shape for two vortices of opposite circulation), and are correlated only in the ensemble, which restores it.

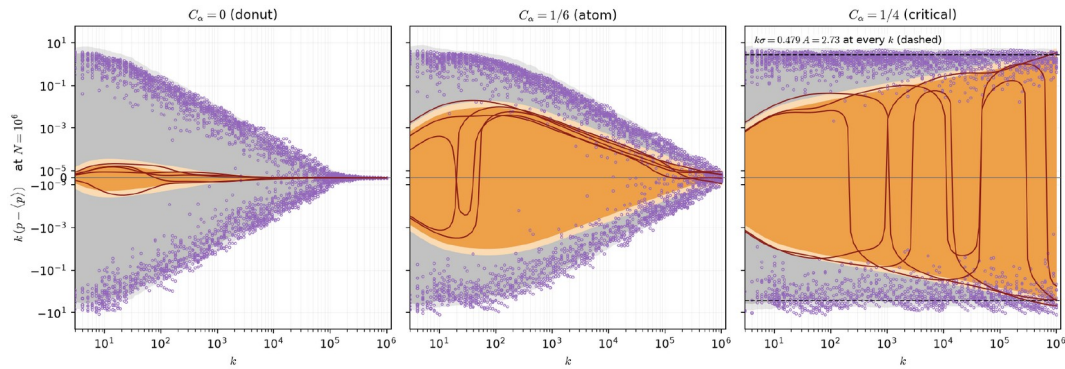


Figure 1. k -multiphoton observables for $2 \leq k \leq 10^6$ showing the perimeter deficit of a k -gon inscribed in the unit circle from the interferences of two $\text{LG}\ell=\pm 1$ beams in plane. The smooth curves are single-collapse averages and reveal a deterministic structure, resilient to noise and providing much stronger estimators than ensemble averages, which are the scattered purple points, that statistical noise has shattered into a cloud distributed at the edge of the standard deviation of their distribution (grey shadow). The Orange shadows are the standard deviation of U-statistics for single collapses. Three cases are considered that correspond to particular quantum states found in thermal light: left-most column correspond to uncorrelated light, central one to the atom of the thermal distribution and right-most to random-phase coherent states, which exhibit various critical behaviours, seen here as the breakdown of self-averaging: more data points lead to stronger departures from the ensemble.

We test this picture by imaging two interfering thermal Laguerre–Gauss vortices with a single-photon avalanche diode camera. Each frame of hundreds to thousands of photons is one collapse of the multiphoton wavefunction [2] and reveals the symmetry-broken structure it was sampled from: a donut, a broken donut or a dipole. Do averages within one collapse agree with averages over many? They do for most states, but this ergodicity breaks down at the classical boundary $C_\alpha = 1/4$, where the one-body density touches zero: single collapses then do not self-average, however many photons they hold. Exhausting all the k -photon subsets of one frame yields smooth, noise-free structures that ensemble averages shatter into statistical noise (Fig. 1). Stripped of their confounding factors, Glauber’s correlators become probability densities on multiphoton configuration spaces, where classical and quantum correlations differ only in contrast. These results bear on any protocol that extracts information from multiphoton averages, such as spatial photonic Ising machines [3,4].

[1] D. E. Salazar and F. P. Laussy, arXiv:2604.16283 (2026)

[2] N. Armaou et al., in preparation (2026)

[3] D. Pierangeli, G. Marcucci and C. Conti, Phys. Rev. Lett., 122, 213902 (2019)

[4] D. Veraldi et al., Phys. Rev. Lett., 134, 063802 (2025)

The scope of the Hybrid Photonics and Materials (HPM 2026) spans from fundamental physics to applications of phenomena related to hybrid light-matter excitations and photon-mediated interactions of disparate material systems.