Collective Multi-mode Effects in Quantum Optics

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Controlling the photon emission of quantum systems is at the heart of a number of fields ranging from quantum information processing to single-molecule spectroscopy. A way to tune the spontaneous emission rate and directionality of a quantum emitter is to place it in a suitably designed photonic structure. Much of the earlier work has focused here on the resonant coupling of the emitter to a single, carefully chosen mode of this photonic structure with favorable emission properties, while the coupling to the rest of the modes of the photonic environment is regarded as having a parasitic influence. This approach results in stringent requirements on the spectral and spatial overlap of the emitter and the resonant mode in question. Here we investigate the opposite approach: coupling an emitter to a large number of modes of a cavity. In particular, we show how this multi-mode coupling can be engineered to lead via interference to a robust collective enhancement of directionality which is more pronounced than that of each mode.