Optical Parametric Amplification for the Detection of Quantum States

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Optical quantum information science promises significant advancements in photonic technologies and heralds a new era of applications, from quantum communication to continuous-variable quantum computing. Its success relies on the efficient generation and, crucially, the detection of quantum states.

In recent years, optical parametric amplification (OPA) has attracted growing attention as a powerful technique for all-optical quadrature detection, offering a loss-tolerant, broadband alternative to conventional homodyne schemes. In fact, it has demonstrated strong performance in squeezing detection across various optical platforms and has even been successfully applied to complete quantum state tomography. Here, I present the recent progress we have made in advancing OPA as a tool for quantum state detection.

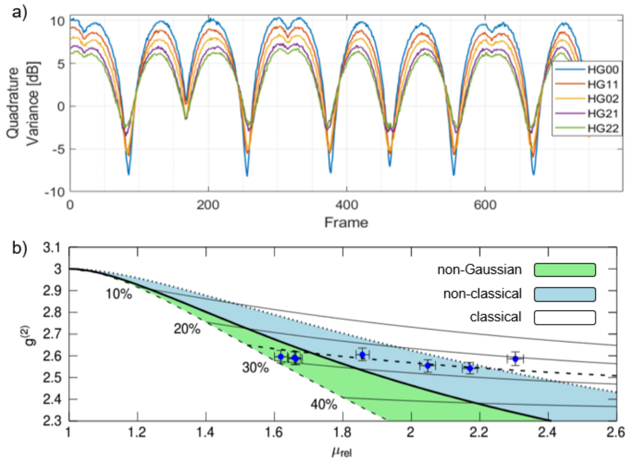

Figure 1: a) Real-time monitoring of the squeezing of different HG modes. b) Non-Gaussianity witness of a heralded quasi-single photon state as its brightness increases

We first explored and leveraged the intrinsic multimode nature of an OPA to simultaneously retrieve the squeezing information for multiple modes. As illustrated in Fig. 1(a), we show real-time monitoring of the squeezing of various spatial Hermite-Gaussian (HG) modes, achieving up to 7.9 dB of squeezing in the fundamental mode. To the best of our knowledge, this is the first demonstration of the real-time monitoring of multimode squeezing. In turn, this achievement paves the way for the efficient, real-time characterization and detection of individual links within a cluster state. This work completes the set of capabilities needed for robust multimode squeezed light detection and significantly expands its applicability in high-dimensional quantum technologies.

Beyond squeezing, non-Gaussianity plays an even more critical role in enabling advanced applications, including universal quantum computing. Therefore, the certification of non-Gaussian quantum states is of high importance. Traditionally, this has relied on single-photon detectors and coincidence measurements. In our second work, we show that OPA, combined with direct intensity measurements, can efficiently witness both non-Gaussianity and non-classicality, without the need for single-photon detectors. As shown in Fig. 1(b), we successfully track the non-Gaussianity witness of a heralded quasi-single-photon state as we increase its brightness, demonstrating the OPA sensitivity to the degradation of quantum features with increasing multiphoton contributions. We believe these works establish OPA as a powerful and practical tool for advancing quantum information processing.