Theory of High-Gain Cavity-Enhanced Parametric Down-Conversion

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Pulsed cavity-based spontaneous parametric down-conversion (SPDC) offers a promising platform for the generation of highly squeezed, single-mode states of light. The resonant enhancement of a cavity has proven useful for realising a high degree of squeezing, and tailoring of the pump profile has been demonstrated to produce desirable optical mode isolation. Designs combining these approaches have seen applications in CV quantum information [1], but analysis of the trade-offs between squeezing and mode isolation are lacking. Seeking theoretical insight, we develop a framework to model SPDC in structured dielectric media and apply it to a cavity-based source.

Our model builds on previous perturbative treatments [2] to develop a theory suitable for sources with significant multi-pair emission. To do so we work with linear Heisenberg equations of motion for the field creation and annihilation operators, obtained with the approximation of a non-depleted pump. Numerical methods then allow for exact solutions even in the case of a strong nonlinear response [3]. Leveraging the group symmetries of the dynamics, we decompose the output to a set of squeezers acting on broadband spatial modes, enabling direct calculation of the effective mode number and degree of squeezing. We develop a general framework built on the normal modes of arbitrary dielectric structures, which leads to a practical input-output theory. An overview of this approach is depicted in Fig. 1.

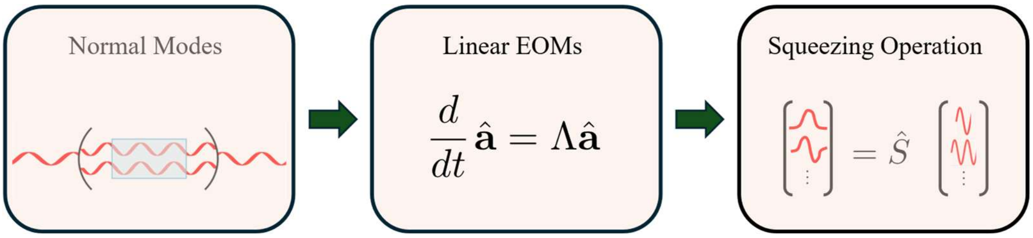

Fig. 1: *Procedure leading from normal modes of the system to a multimode squeezing operator*

As a demonstration of our theoretical framework, we develop a simple model of SPDC in a hemilithic cavity. Through numerical calculations, we explore the interplay between squeezing, mode isolation and bandwidth within realistic device parameters, with the aim of guiding current experimental methods.

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