I. INTRODUCTION

A significant engineering discipline has been built around the ability to fabricate micron- and nano-scale opto-mechanical systems of extraordinary variety. The emerging field of quantum optomechanics extends this ability towards a fully quantum domain enabling a new scientific discipline that aims to establish mechanical resonators as novel systems for quantum science. In combination with quantum optics techniques and new fabrication methods, highly nonclassical states of motion, such as a vibrational energy eigenstate, squeezed states and even entangled states can be prepared and coherently manipulated [1–3]. This now provides a new approach for controlling the mutual interaction between light and mesoscopic structures, which is one of the eminent goals in quantum information science [4] and of importance for fundamental experiments at the quantum-classical boundary [5].

Almost all previous investigations in opto-mechanics have presupposed conventional optical sources, well described by statistical mixtures of coherent states. Some early theoretical work considered the possibility of using squeezed light in an opto-mechanical setting[6] and advanced LIGO may make some of these suggestions an engineering reality[7]. More generally speaking, most of the current proposals to achieve (opto-)mechanical quantum states are restricted to the class of Gaussian states. To go beyond this regime requires additional non-linearities, either in the interaction or in the measurement process. One example is the use of single photons to prepare macroscopic mechanical superpositions [8, 9]. Current opto-mechanical systems, however, still exhibit couplings below the necessary single-photon interaction strength. In this paper we propose a scheme that allows to achieve single-photon optomechanics in presently available systems. The main idea is to enhance the single-photon coupling strength by the presence of a strong pump field. It has recently been shown both in theory [10, 11] and experiment [12] that this allows to enter the strong coupling regime of an opto-mechanical system. We show that in such a case, even for small intrinsic single-photon coupling, a single photon excitation of the cavity can be reversibly transferred to the vibrational motion of a mechanical resonator. We study the dynamics of this process and show that it can be detected as temporal oscillations in the cavity emission. This is in close analogy to optical three-wave mixing, where the pump field converts excitations in the optical signal mode (here: the cavity photons) into excitations in the optical idler mode (here: the vibrational phonons) and vice versa.