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Nonclassicality criteria applied to excitations in Bose-Einstein condensates

In the recent literature it has been proposed that the well-established nonclassicality criteria from the field of quantum optics can be directly applied to the case of excitations in quantum matter-waves, i.e. Bose-Einstein condensates (BECs). In particular, it has been suggested that the number- difference squeezing parameter, also known as the two-mode variance which is related to the Cauchy-Schwarz inequality, can be applied to the occupation of two parametrically excited modes of opposite momenta to delineate classical from nonclassical states. In this paper we calculate the two-mode variance and Cauchy-Schwarz inequality for the model of a homogeneous Bose gas undergoing an arbitrary modulation in the interaction parameter. We show that these correlation measures are equivalent to entanglement of counter-propagating atomic modes in the quantum theory. We then demonstrate that nevertheless they are insufficient to distinguish between classical and nonclassical origins of fluctuations in a BEC by comparing the quantum result with the predictions of a semiclassical field theory based on the Gross-Pitaevskii equation.

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